ORIGIN OF PALEOZOIC SHALE OF FLORIDA

A THESIS

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SUMMARY

From the evidence of faunal distribution, it has been suggested that Florida used to be attached to northwestern Africa during Paleozoic time. Later, North America combined with Florida in Early Mesozoic time. If Florida and northwestern Africa used to be the same continent during the Paleozoic, the sources of sediment that supply those two areas should be the same. Clay minerals in Paleozoic sediment of Florida, Appalachian Mountains, Ouachita areas were analyzed by the method of x-ray diffraction. Clay suites of subsurface Paleozoic sedimentary rocks from Florida are more similar to Paleozoic clay suites of northwestern Africa than those of the Appalachian Mountains and Ouachita areas. It is possible to explain that Florida and northwestern Africa had similar source areas during the Paleozoic time.

CHAPTER I

INTRODUCTION

A great deal of evidence has been cited as proof of the drifting apart of North America, and Europe and northwestern Africa. The evidence is ancient life and environments, ancient climates, remanent magnetism of rocks, and features of the ocean floor (Tarling and Tarling, 1971). There is some evidence to prove that the Atlantic closed and then reopened. The role played by Florida is to be considered in this work. Some evidence shows that Florida used to be a part of northwestern Africa, and that later North America moved toward Europe and northwestern Africa. So Florida was combined with North America as North America attached to northwestern Africa. The relations between Florida and continental drift will be described in the following pages.

Wilson (1966) found differing distributions of faunal realms in North America, Europe, and northwestern Africa (Figure 1). Most of the "Pacific" faunal realm (vertical shading) occurs in North America, and most of the "Atlantic" faunal realm (horizontal shading) occurs in Europe and northwestern Africa. But there are some irregularities in the distribution: the "Atlantic" faunal province is present in

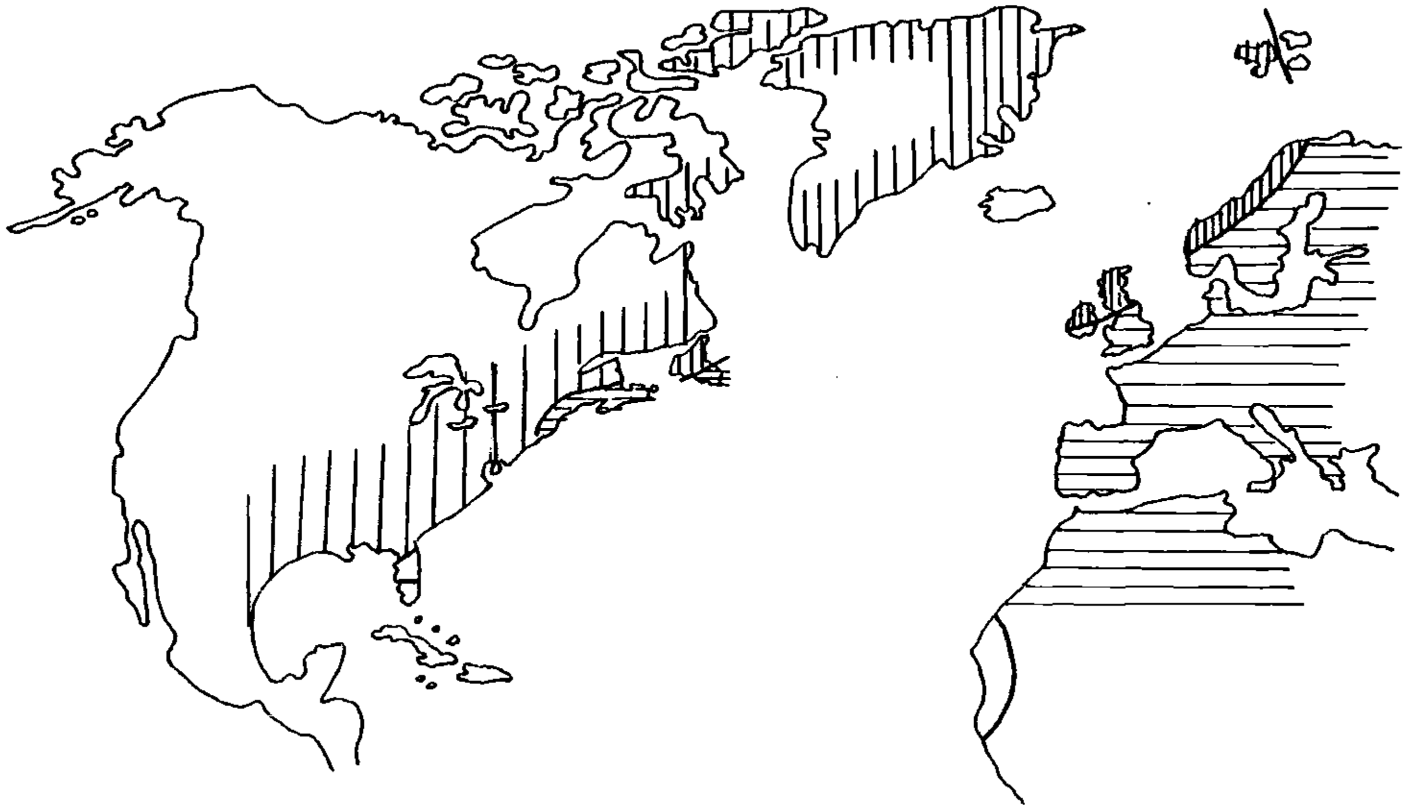

Figure 1. The Distribution of "Pacific" (vertical shading) and "Atlantic" (horizontal shading) Faunal Realms. (After Wilson, 1966).

the British Isles, western Spitsbergen, and western Scandinavia. From the unusual distribution of these faunal realms, it is proposed that, in Early Paleozoic time, a proto-Atlantic Ocean existed that formed the boundary between the two realms, and that during Middle and Late Paleozoic time the ocean closed by stages, bringing dissimilar facies together (Figure 2). The history proposed for the North Atlantic region can be stated very briefly as follows:

a) From the Late Precambrian to the close of Middle Ordovician time an open ocean existed in approximately, but not precisely, the same location as the present North Atlantic (Figure 3).

b) From Late Ordovician time to Carboniferous time, this ocean closed by stages.

c) From Permian to Jurassic time there was no deep ocean in the North Atlantic region. Florida was completely linked to North America by this time.

d) Since the beginning of Cretaceous time the present Atlantic Ocean has been opening, but this reopening did not follow the precise line of juncture formed by the closing of the Early Paleozoic Atlantic Ocean. The result is that some coastal regions have been transposed (Figure 2) and Florida has been attached to North America. Four lines of evidence suggest that this proposal is reasonable.

First, this reconstruction of geological history provides a unified explanation of the changes in rock types,

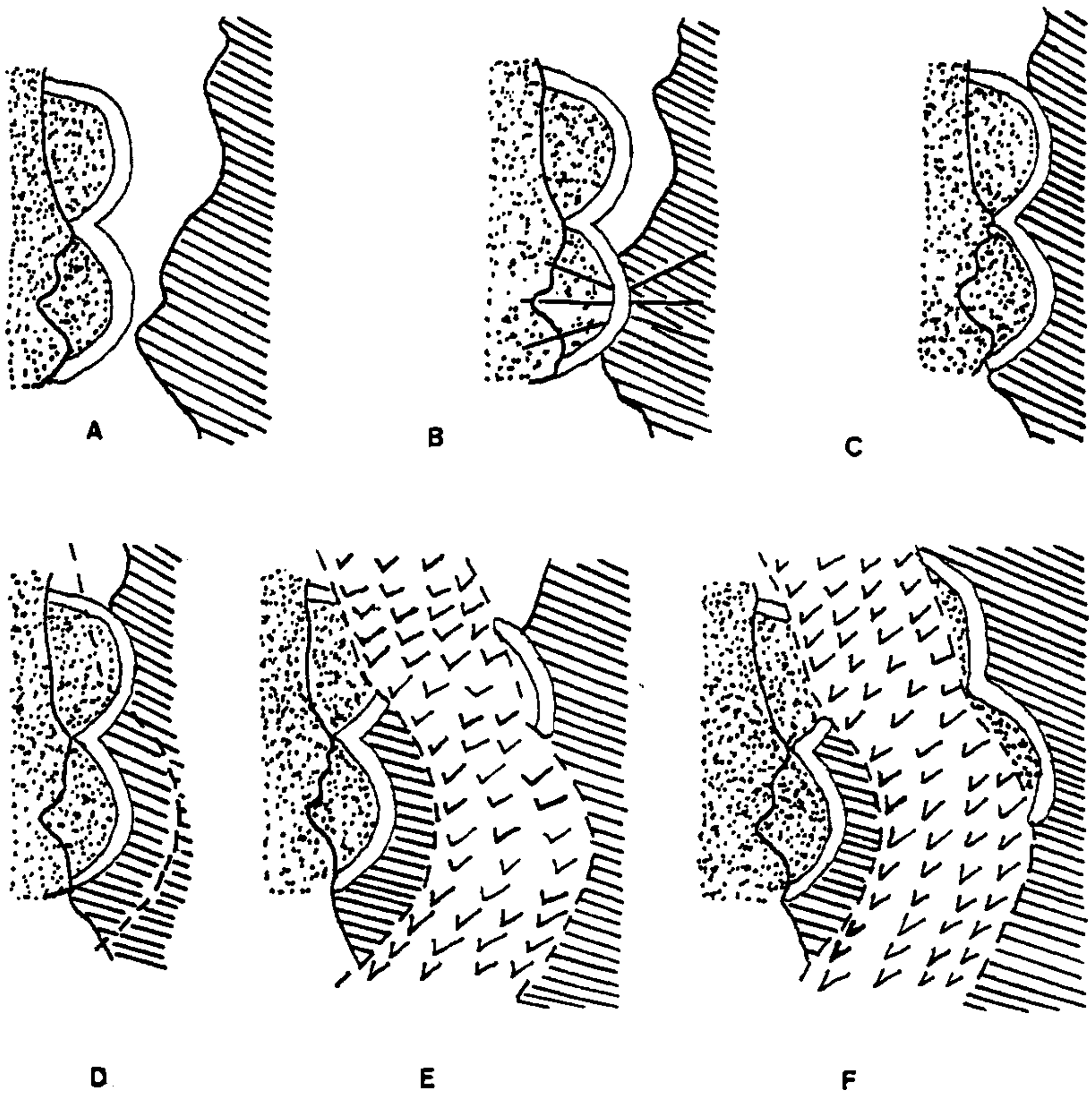

Figure 2. Hypothetical Model of the Closing and Reopening of the Atlantic Ocean (see explanation on page 6). (After Wilson, 1966).

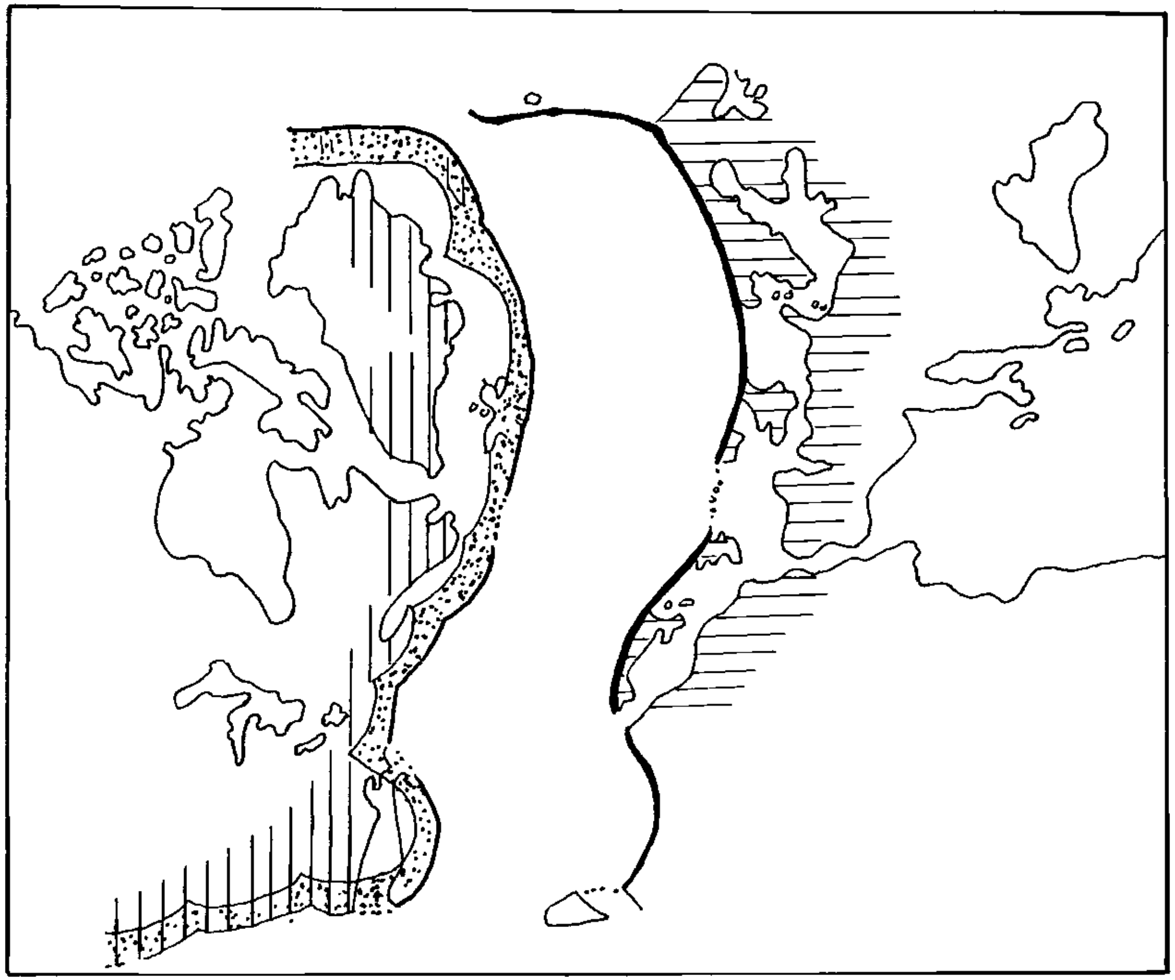

Figure 3. The North Atlantic Region in Early Paleozoic Time (stippled area shows the island arcs). (After Wilson, 1966).

fossils, mountain orogenic episodes and paleoclimates.

Second, wherever the juncture between parts of different faunal realms is exposed, it is marked by extensive faulting, thrusting, and crushing.

Third, there is evidence that the juncture is along the eastern side of a series of ancient island arcs (Figure 2).

Fourth, the fit appears to meet the geometric requirement, that during a single cycle of closing and reopening of an ocean, in any latitudinal belt of the ocean, only one of the pairs of opposing coasts can change sides (Figure 2). The explanation of Figure 2 is:

a) A closing ocean, with island arcs on one coast, separating two different faunal realms;

b) First contact between two opposite sides of a closing ocean;

c) The ocean closed by overlap of the opposite coasts;

d) A possible line (dashed) along which a younger ocean could reopen;

e) A new ocean (checked) opening in an old continent;

f) A geometrically impossible way for a younger ocean to open.

Whittington and Hughes (1972) reconstructed Ordovician paleogeography and faunal provinces from trilobite distributions. By tracing the distribution of Arenig-Llanvirn series, the relation between paleogeography of the Early Ordovician and trilobite faunal provinces can be presented (Figure 4). Figure 4 suggests that during the Early Ordovician, Florida was attached to northwestern Africa. The faunal type Selenopeltis has been found in a boring in northwestern Florida and is also found in northwestern Africa, however the faunal types of Florida and North America are different. The Bathyurid fauna of North America is also known in northwestern Ireland and Scotland, western Norway, and Spitsbergen. The proto-Atlantic ocean acted as the barrier to faunal migrations between the Bathyurid provinces and Selenopeltis provinces. The Llanvirn faunas of Kazakhstan are like those of North America, that is, also of of Bathyurid type. By the same method, we can construct the paleogeographic map of the Late Ordovician from the relation of Ashgill series (Figure 5). According to Whittington and Hughes (1972) Florida was attached to northwestern Africa, but separated from North America during the Ordovician.

If Florida and northwestern Africa used to be attached during the Early Paleozoic, the original sources of sediment that supplied Florida and northwestern Africa should be the same. Using this idea, we can assume that the Lower Paleozoic shale of Florida formed when Florida was attached to Africa. Clay minerals are the major component in shales. The main idea of this thesis is the comparison of the kinds

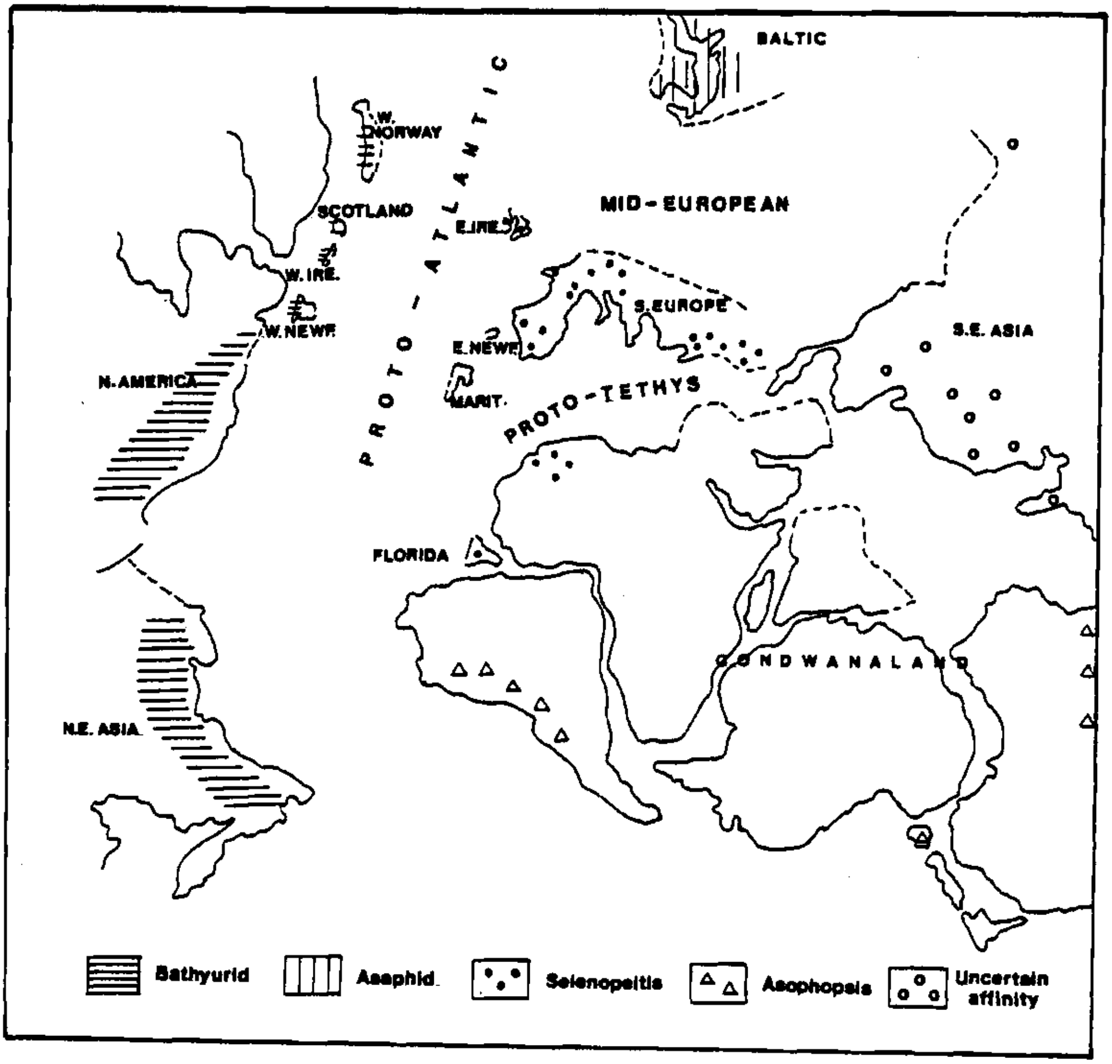

Figure 4. Construction of Southern Hemisphere During Early Ordovician using Distribution of Arenig-Llanvirn Series. Abbreviation for Geographic Areas: W.IRE-Northwestern Ireland, E.IRE-Southeastern Ireland, E.NEWF-Eastern Newfoundland, W.NEWF-Western Newfoundland, MARIT-Maritime Provinces. (After Whittington and Hughes, 1972).

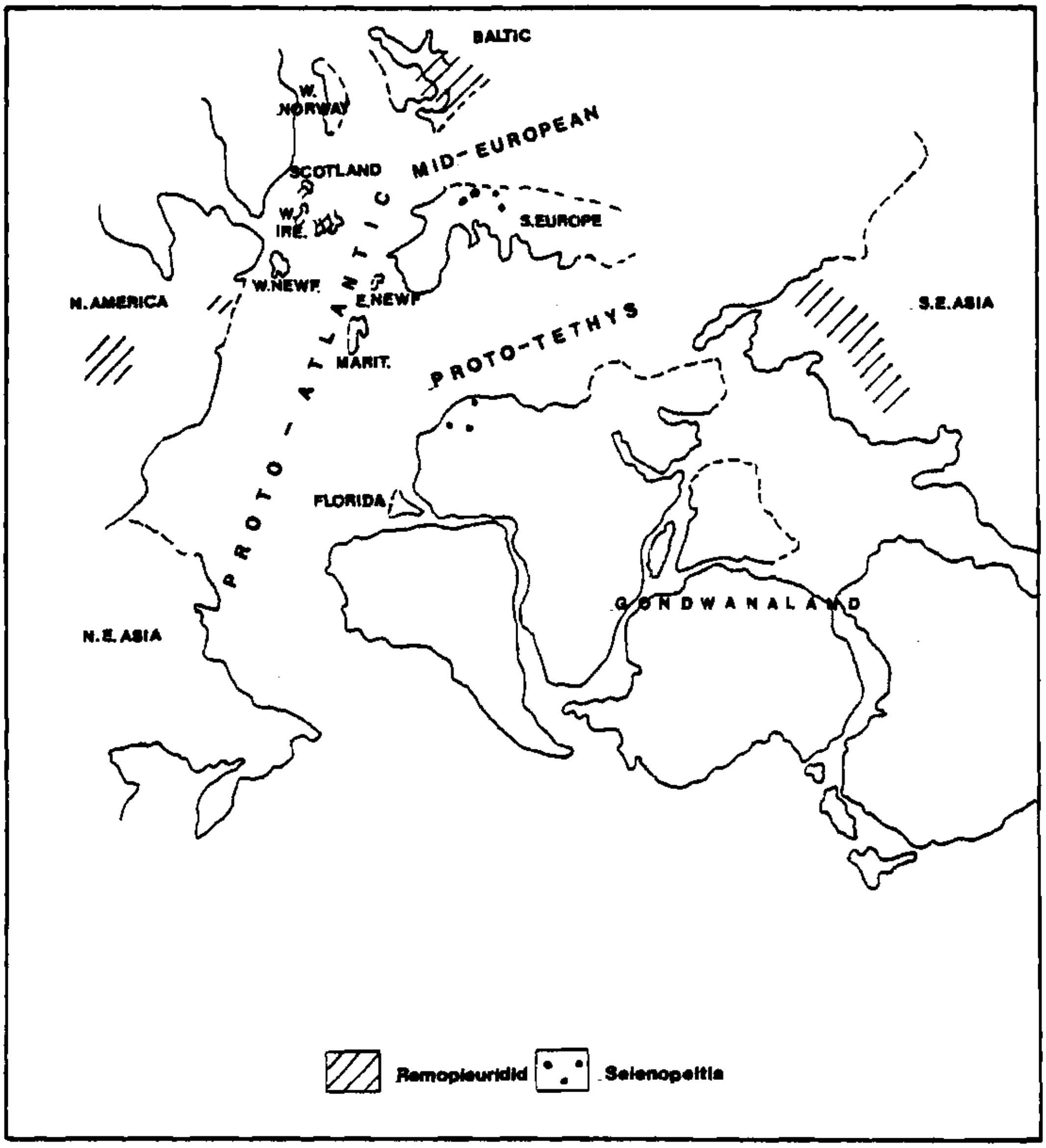

Figure 5. Construction of Southern Hemisphere During Late Ordovician Using Distribution of Ashgill Series. See Explanation of Figure 4 for Abbreviations of Geographical Names. (After Whittington and Hughes, 1972).

and amounts of clay minerals in northwestern Africa and eastern North America (Florida, Appalachian mountains, and Ouachita area). Paleozoic sedimentary rocks of Florida were analyzed for the type and relative amount of clay minerals by the x-ray diffraction method.

CHAPTER II

PROCEDURE

Method of Sample Preparation

1) Grind the sediment (do not crush) into very fine particles (powder).
2) Weigh out 4 grams of sample, then load into a 50 ml beaker.
3) Pour in 15 ml of 0.4 percent calgon.
4) Fill with distilled water to 50 ml beaker level, then stir.
5) Pour the liquid into the blender and blend it for 3 minutes, then pour it back into the 50 ml beaker.
6) Draw the liquid off the surface of the sample with an eye dropper and then drop onto a glass slide and leave it for 24 hours to dry.

NOTICE: The above preparation is for sediment which has no calcium carbonate in it. If it has carbonate, for example limestone or calcareous shales etc., it has to be treated for carbonate first.

Carbonate treatment:

a) After step 2 mentioned above, pour 45 ml of 0.1 N HCl into the 50 ml beaker. The bubbles of carbon dioxide should appear.
b) Stir sample 4-5 times per day for 2 days.

c) Place all liquid and residual sample in a centrifuge tube.

d) Centrifuge it for 15-20 minutes until all residue settles.

e) Pour out supernate, then pour distilled water into the beaker to wash out the HCl. Transfer to the centrifuge tube.

f) Shake the centrifuge tube, and centrifuge it again.

g) Repeat step e) and f) 2-3 times.

After this treatment, the sample should not have any more carbonate, so we can start from step 3 on page 11 and finish through step 6.

After the sample is dried and there is a thin film of clay coated on the glass slide, place it in a glycol bath for 24 hours to glycolate it. After 24 hours the sample is ready to be x-rayed. Clays have platy crystals. After they are dried on a glass slide, the (001) crystal faces will always lie parallel to the surface of the glass slide. When x-rays strike the clay powder, the x-ray will strike the (001) crystal face and yield the (00ℓ) reflections and produce an x-ray pattern on the strip chart recording. Differing incident angle (θ) on differing types of clay minerals produce different (00ℓ) reflections. The first reflection is (001), the second is (002), the third is (003), and the fourth is (004) and so on. Generally, the more important are the (001) and (002) reflections, because they predominate in the strip chart recordings. From the angle of incidence for each reflection, a "d" value may be calculated by Bragg's

Law. The (001) reflection gives the "d" value of the unit cell. The "d" value for the (002) reflection is half the length of the "d" value for (001), so the "d" values are related as follows: (002) = 1/2(001), (003) = 1/3(001), (004)= 1/4(001), and so on. Grim (1968) described the "d" values for the (001) reflections of each clay mineral as follows:

Kaolinite: (001): 7.16Å, (002): 3.57Å, (003): 2.37Å

Chlorite: (001): 14.2Å, (002): 7.13Å, (003): 4.73Å, (004): 3.55Å

Illite: (001): 10Å, (002): 5Å, (003): 3.33Å

Glycolated montmorillonite: (001): 17Å, (002): 8.5Å, (003): 5.6Å

Figures 6, 7, 8, and 9 show examples of the x-ray patterns.

Complications with Chlorite and Kaolinite Reflections

The (001) peak (14.2Å) of chlorite does not appear as well as the (002) peak (7.13Å); at the same time, the (001) peak of kaolinite appears at 7.16Å. Thus, the (002) peak of chlorite and (001) peak of kaolinite might appear at nearly the same position in the x-ray pattern. The presence or absence of chlorite and kaolinite can be determined by the (004) peak of chlorite and the (002) peak of kaolinite. If the clay sample has a chlorite (004) peak which has a "d" value 3.55Å, it should show at $2\theta = 25.2°$. If kaolinite is contained in the clay sample, the (002) peak which has a "d"

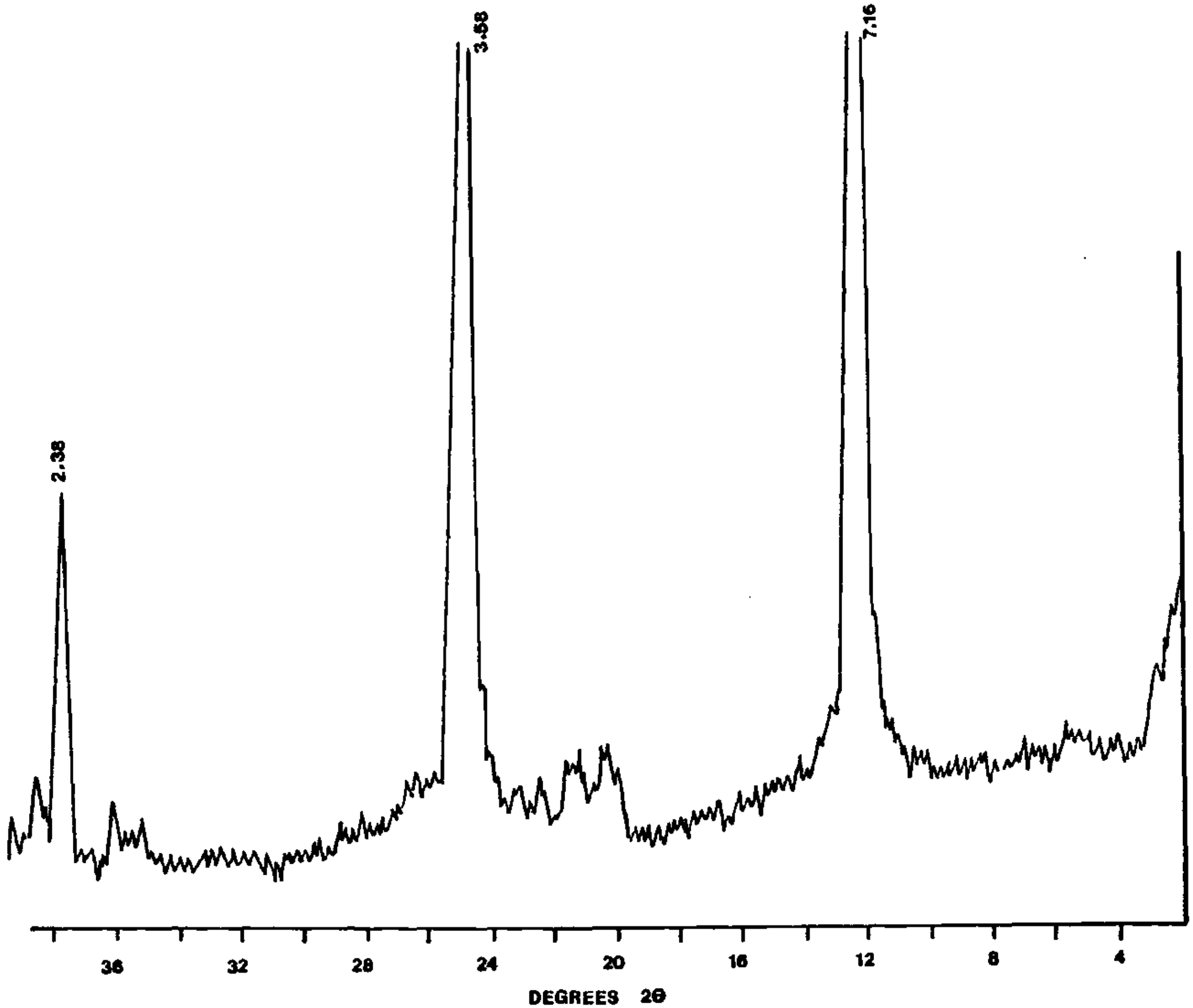

Figure 6. X-Ray Pattern of Kaolinite. (After Weaver, Personal Communication).

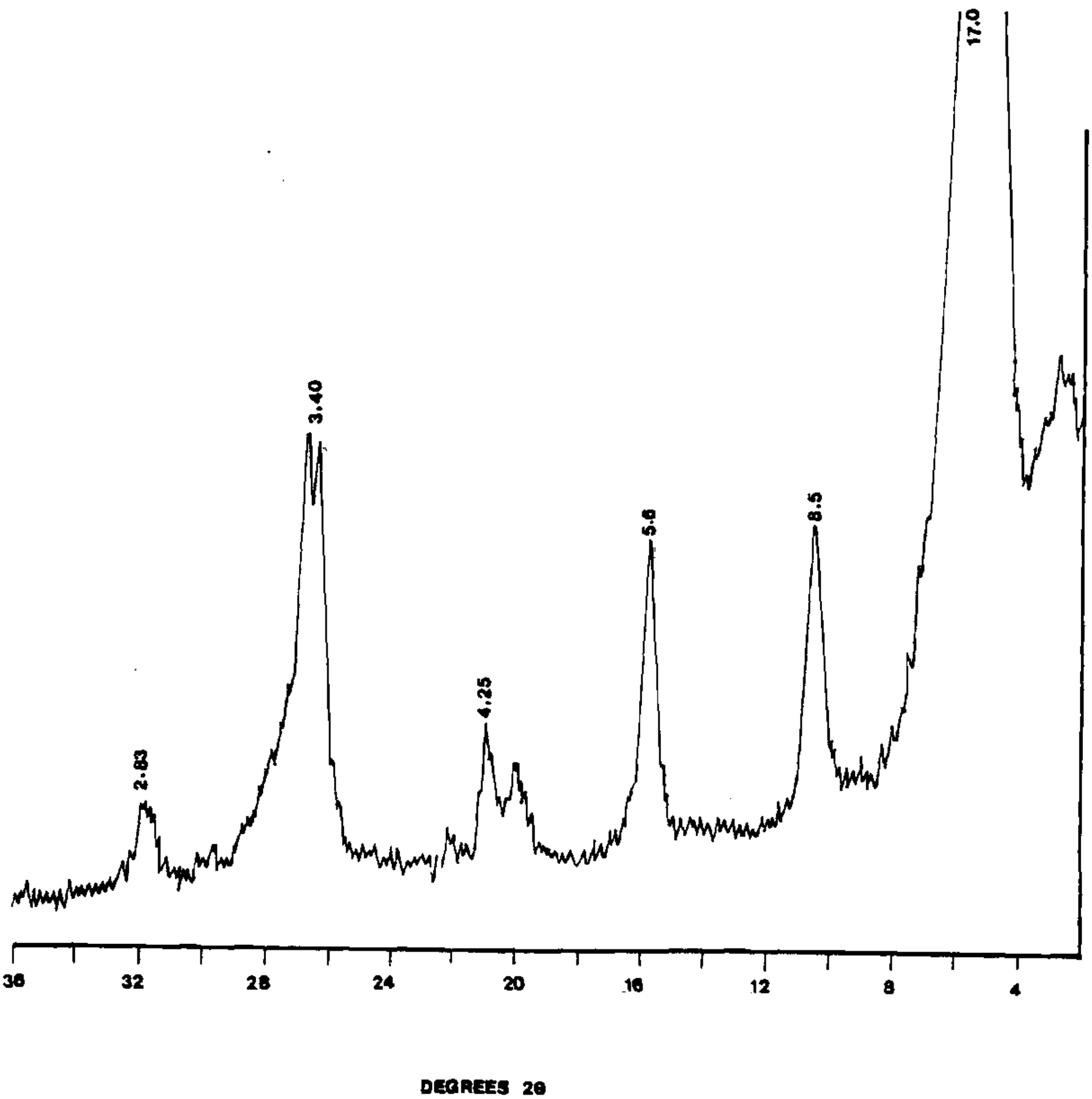

Figure 7. X-Ray Pattern of Montmorillonite. (After Weaver, Personal Communication).

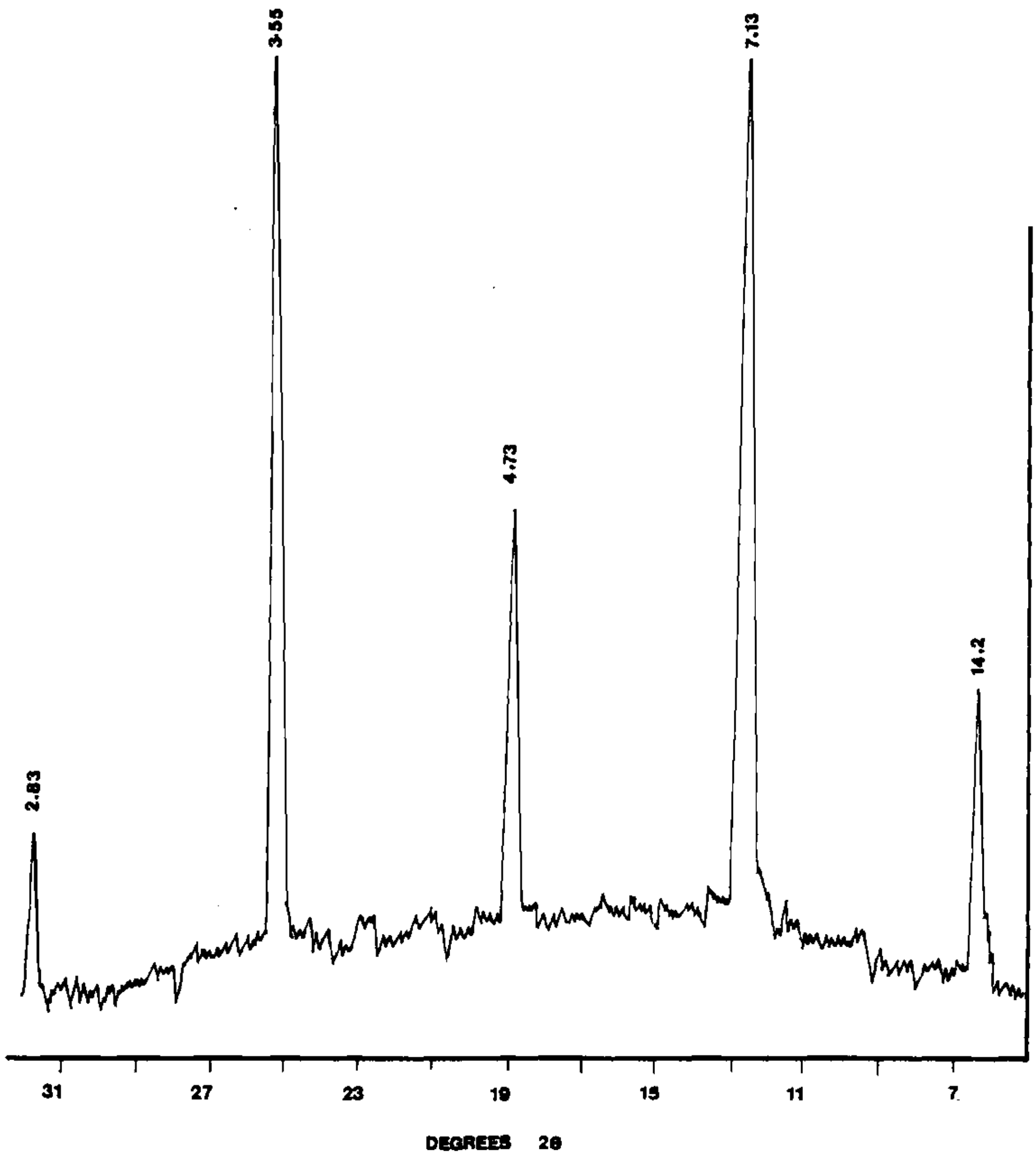

Figure 8. X-Ray Pattern of Chlorite. (After Weaver, Personal Communication).

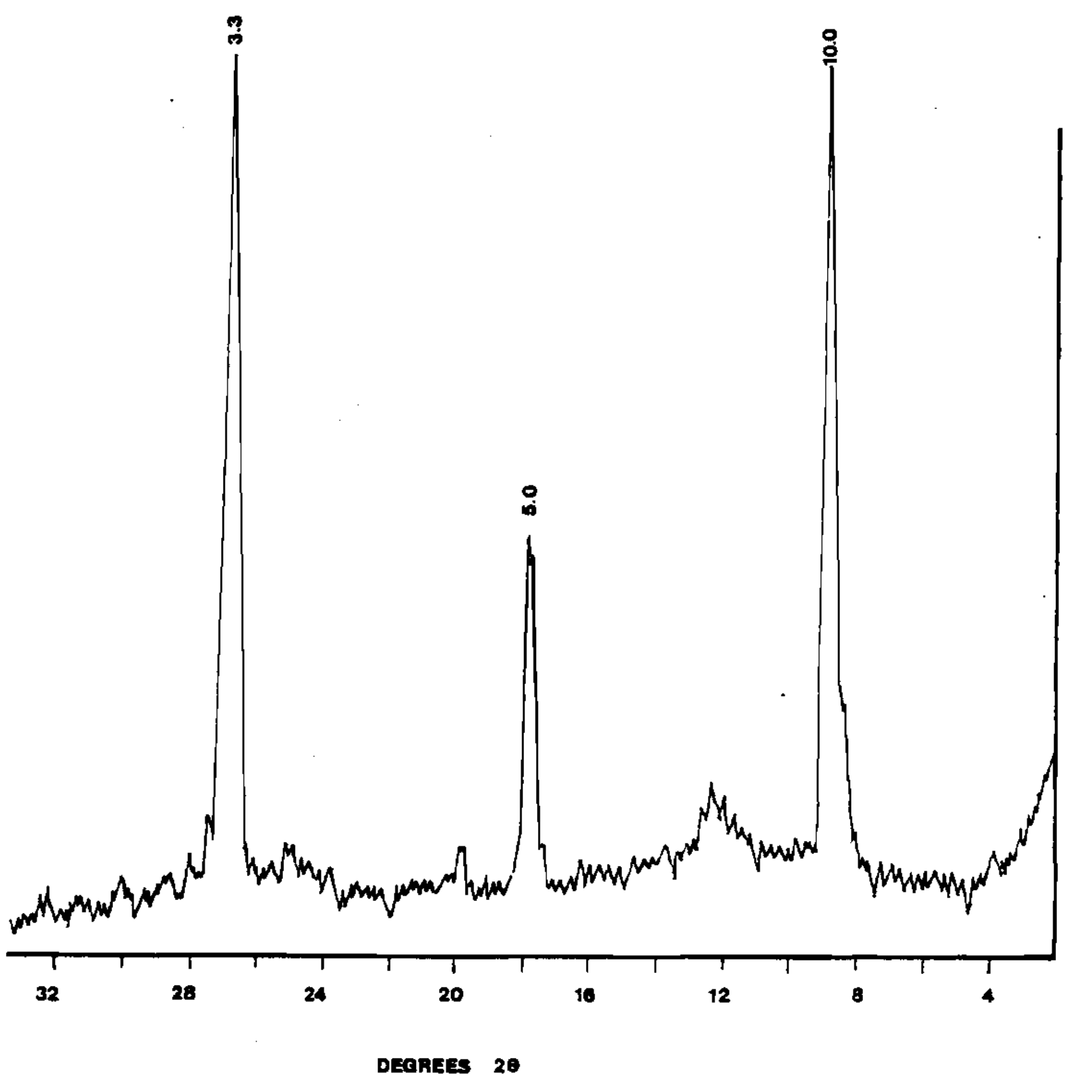

Figure 9. X-Ray Pattern of Illite. (After Weaver, Personal Communication).

value of 3.57Å should show at $2\theta = 25.0°$

Clay Percent Calculation

After getting the complete x-ray pattern, the (001) peak of each kind of clay mineral can be identified. Then one may calculate the percentage of each clay from the (001) peak. The calculation methods are:

1) Draw a background curve under all (001) clay peaks.

2) Measure the area under the (001) peaks.

3) Divide the area by correction factor; the correction factor depends on the clay mineral. For montmorillonite divide by 3; for illite divide by 1; for kaolinite and (002) of chlorite divide by 2.5.

4) Calculate the corrected area of each peak as a percentage relative to the sum of corrected peak areas. The area percentage corresponds to the percentage of clay mineral.

If the sample contains both kaolinite and chlorite, calulate the ratio of the areas of chlorite (004) and kaolinite (002) peaks. Then, multiply the fraction of each by the percentage of clay at 7.16Å to get the amount of chlorite and kaolinite.

CHAPTER III

PALEOZOIC AND MESOZOIC ROCKS OF FLORIDA

Paleozoic igneous basement rocks are found in the subsurface in Florida. Paleozoic and Mesozoic sedimentary rocks lie on the top of the igneous basement. The "basement" is defined as the igneous rocks of the subsurface. They are composed of diabase, basalt, gabbro, rhyolite, granite, andesite, diorite, etc. Mahew (1974) described the age of the basement rocks. The oldest age is metabasalt in Volusia County (524 million years), within the range of Cambrian to Ordovician; some of the igneous rocks are of Mesozoic age. The words "coastal plain floor" are defined as the Paleozoic igneous basement and sedimentary rocks. Cretaceous sedimentary rocks of the Coastal Plain overlie the truncated surface (coastal plain floor) of igneous and sedimentary rocks.

Applin and Applin (1965) described the Mesozoic rock of Florida. Their work is summarized in the following. Carbonate rock of the Mesozoic lies above Paleozoic rock. The Fort Pierce formation makes up the bottom layer of Mesozoic rock. The Comanche series lies on top of the Fort Pierce formation. Their age is Cretaceous. The Comanche series is divided into three groups: the bottom rock is bed of Trinity age, the middle is bed of Fredericksburg age, and the top is bed of Washita age. Figure 10 shows the sequence of Fort Pierce formation and Comanche series.

Paleozoic Sedimentary Rocks and Clays

Most of the samples are from northern and northwestern Florida between 30° and 31° N latitude. All of the samples are cuttings of limestone, limy shale, sandstone, shale, etc. The samples were collected and the ages determined by the Department of Natural Resources, Tallahassee, Florida. Spacing of samples is as little as 3 feet to as great as 200 feet. The lithologic explanation is shown in Figure 11. The description of clays in the sedimentary rock is in the following:

Well location: Washington County

Sample interval: 11,400 to 11,560 feet

Sample spacing: 20 feet

Sample description: Arkose, brown color. The bottom rocks are quartzite and meta-arkose.

Age: Cambrian to Lake Precambrian

Clay mineral composition: Illite ranges from 85 to 90 percent, averages 87 percent. Chlorite ranges from 2 to 7 percent, averages 6 percent. Kaolinite ranges from 2 to 7 percent, averages 6 percent.

The percentage of clay minerals is shown in Figure 12.

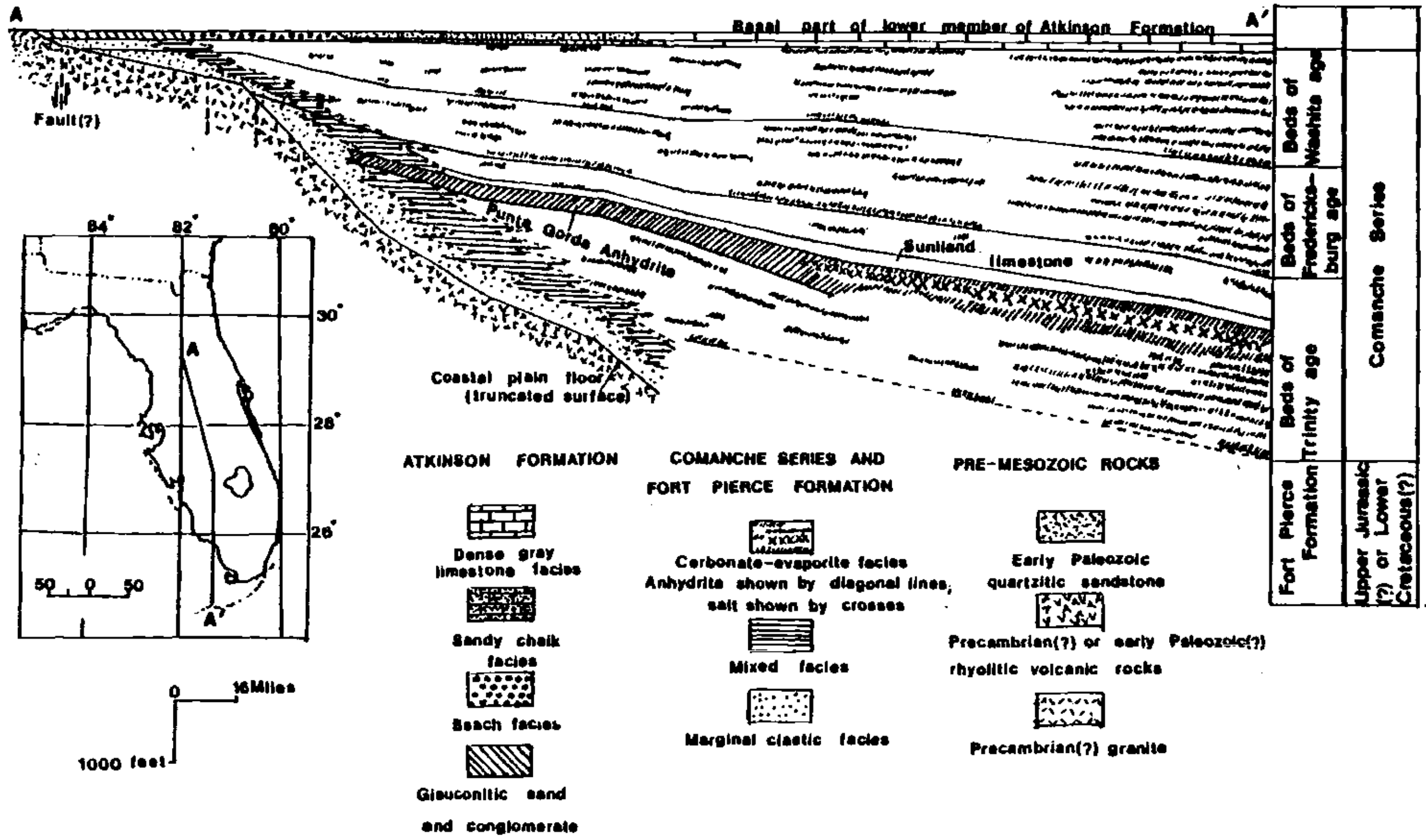

Figure 10. Cross-section of Comanche Series and Associated Rocks. (After Applin and Applin, 1965).

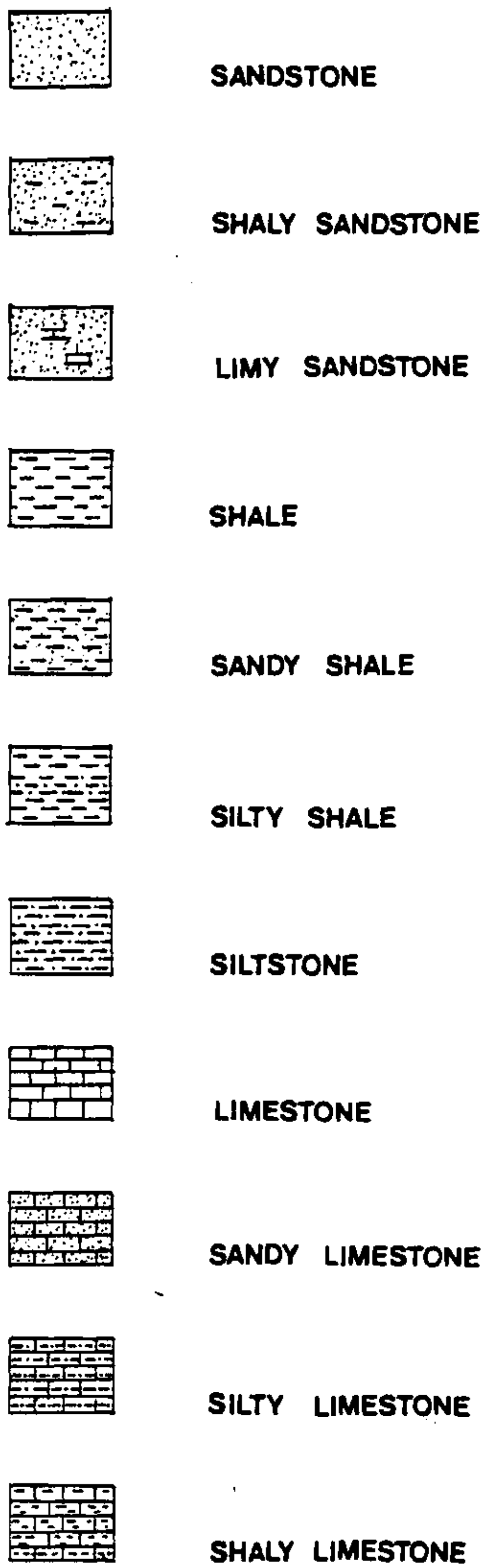

Figure 11. Lithologic Explanation.

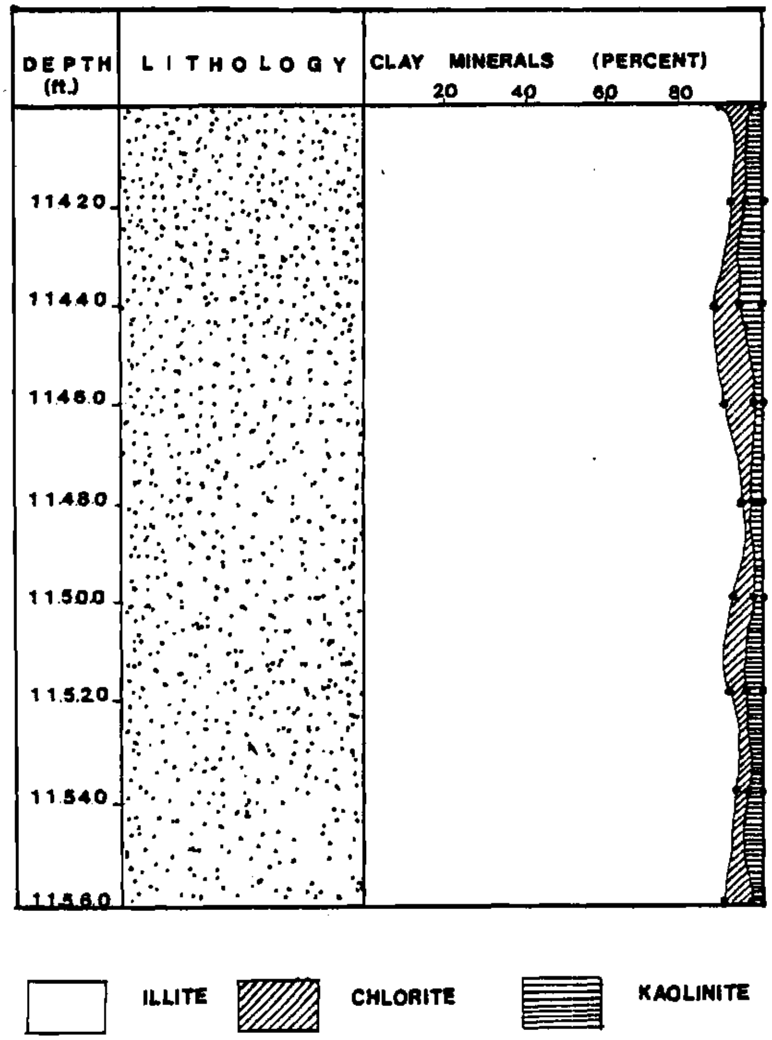

Figure 12. Percentage of Clay Minerals in Cambrian Rocks of Washington County, Florida.

Well location: Washington County

Sample interval: 11,320 to 11,680 feet

Sample spacing: 20 feet

Sample description: Arkose from 11,328 to 11,380 feet, red and quartzes have pink color. Protoquartzite from 11,510 to 11,680 feet.

Age: Cambrian to Upper Precambrian

Clay mineral composition: Illite ranges from 70 to 85 percent, averages 75 percent. Chlorite ranges from 4 to 30 percent, averages 21 percent. Kaolinite ranges from 0 to 16 percent, averages 4 percent.

The percentage of clay minerals is shown in Figure 13.

Well location: Alachua County

Sample interval: 2,600 to 2,850 feet

Sample spacing: 50 feet

Sample description: Quartzitic sandstone

Age: Ordovician

Clay mineral composition: Illite ranges from 53 to 87 percent, averages 67 percent. Chlorite ranges from 13 to 47 percent, averages 33 percent.

The percentage of clay minerals is shown in Figure 14.

Well location: Washington County

Sample interval: 12,200 to 14,000 feet

Sample spacing: Variable

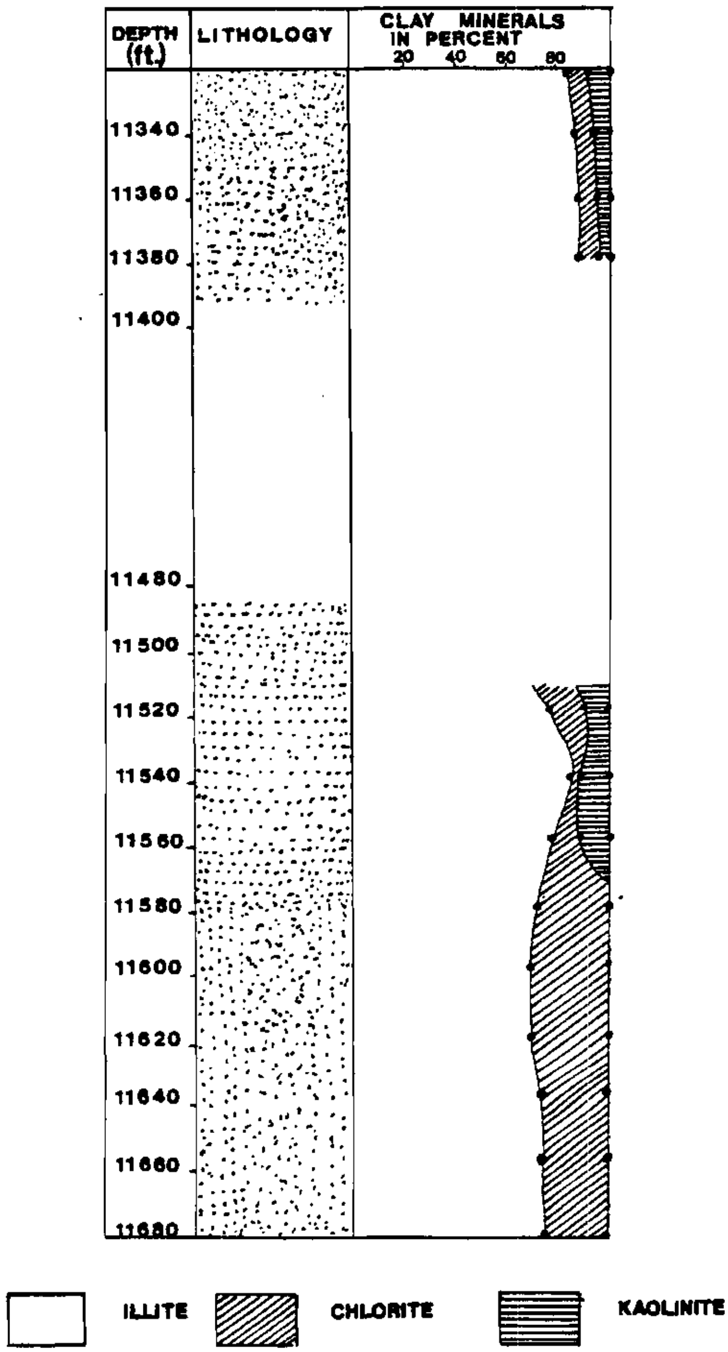

Figure 13. Percentage of Clay Minerals in Cambrian Rocks of Washington County, Florida.

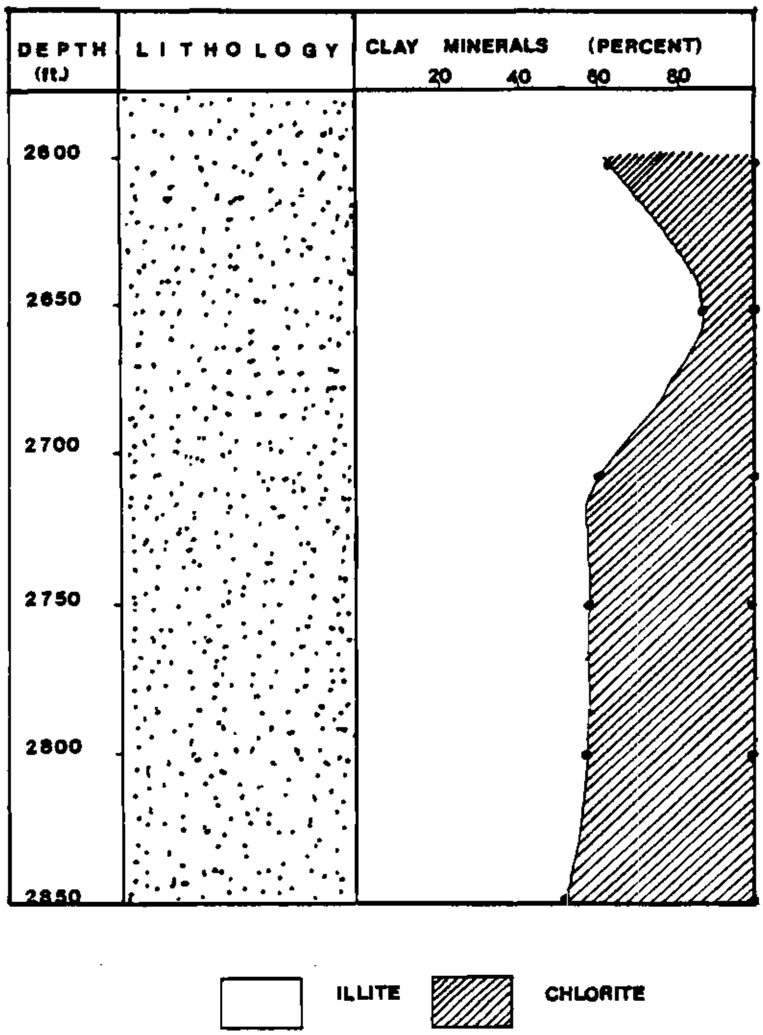

Figure 14. Percentage of Clay Minerals in Ordovician Rocks of Alachua County, Florida.

Sample description: White sandstone, black shale, gray shale, sandy shale, and shaly silt.

Age: Ordovician

Clay mineral composition: Montmorillonite ranges from 0 to 15 percent. Illite ranges from 65 to 92 percent, averages 74 percent. Chlorite ranges from 4 to 23 percent, averages 15 percent. Kaolinite ranges from 1 to 5 percent, averages 2 percent.

The percentage of clay minerals is shown in Figure 15.

Well location: Levy County

Sample interval: 4,500 to 4,750 feet

Sample spacing: Variable

Sample description: Alternation of shale and quartzitic sandstone

Age: Devonian

Clay mineral composition: Montmorillonite ranges from 0 to 62 percent. Illite ranges from 30 to 88 percent, averages 66 percent. Chlorite ranges from 0 to 7 percent, averages 2 percent. Kaolinite ranges from 2 to 26 percent, averages 10 percent.

The percentage of clay minerals is shown in Figure 16.

Well location: Citrus County

Sample interval: 4,700 to 4,800 feet

Sample spacing: 10 feet

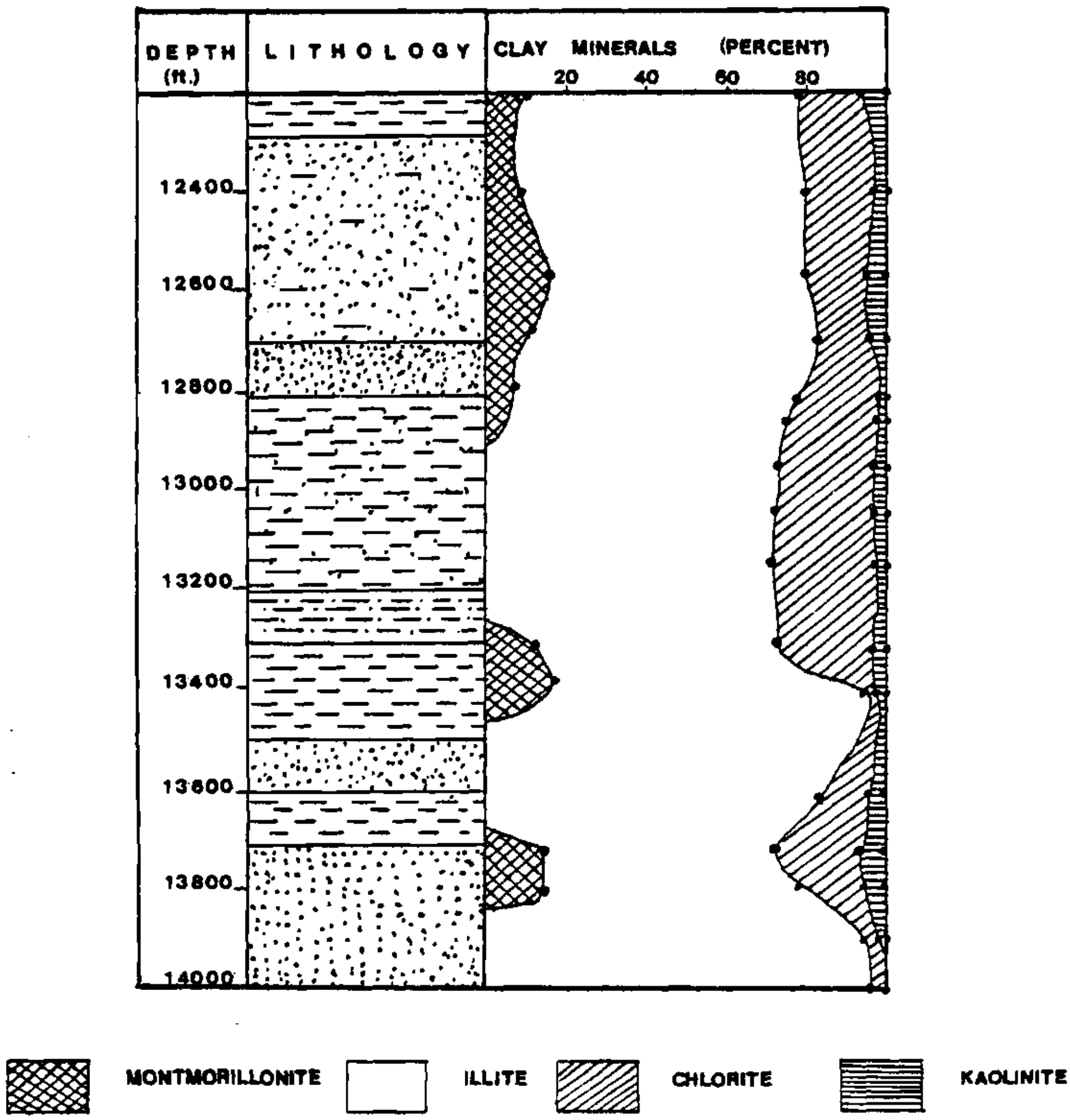

Figure 15. Percentage of Clay Minerals in Ordovician Rocks of Washington County, Florida.

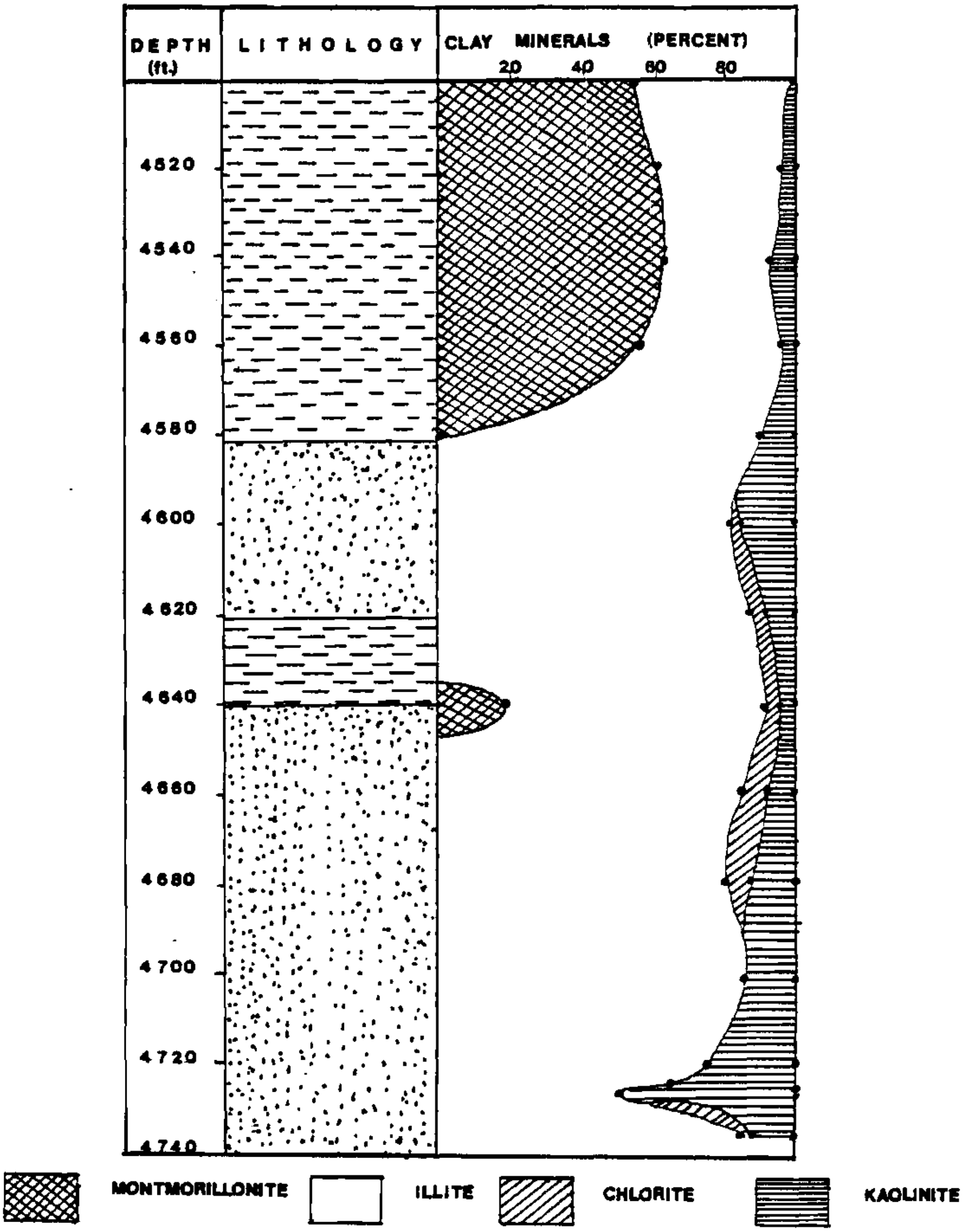

Figure 16. Percentage of Clay Minerals in Devonian Rocks of Levy County, Florida.

Sample description: Shale from 4,700 to 4,710 feet, and quartzitic sandstone from 4,710 to 4,800 feet.

Age: Devonian

Clay mineral composition: Illite ranges from 76 to 90 percent, averages 83 percent. Chlorite ranges from 3 to 9 percent, averages 5 percent. Kaolinite ranges from 7 to 15 percent, averages 12 percent.

The percentage of clay minerals is shown in Figure 17.

Well location: Jackson County

Sample interval: 8,600 to 8,960 feet

Sample spacing: Variable

Sample description: Shaly silt from 8,590 to 8,610 feet, gray shale from 8,610 to 8,665 feet, shaly silt from 8,665 to 8,700 feet, brown shale from 8,700 to 8,770 feet, shaly silt from 8,810 to 8,950 feet.

Age: Devonian

Clay mineral composition: Disregarding montmorillonite, illite ranges from 57 to 80 percent, averages 73 percent. Chlorite ranges from 7 to 16 percent, averages 11 percent. Kaolinite ranges from 11 to 19 percent, averages 17 percent.

The percentage of clay minerals is shown in Figure 18.

Well location: Leon County

Sample interval: 8,300 to 10,400 feet

Sample spacing: Variable

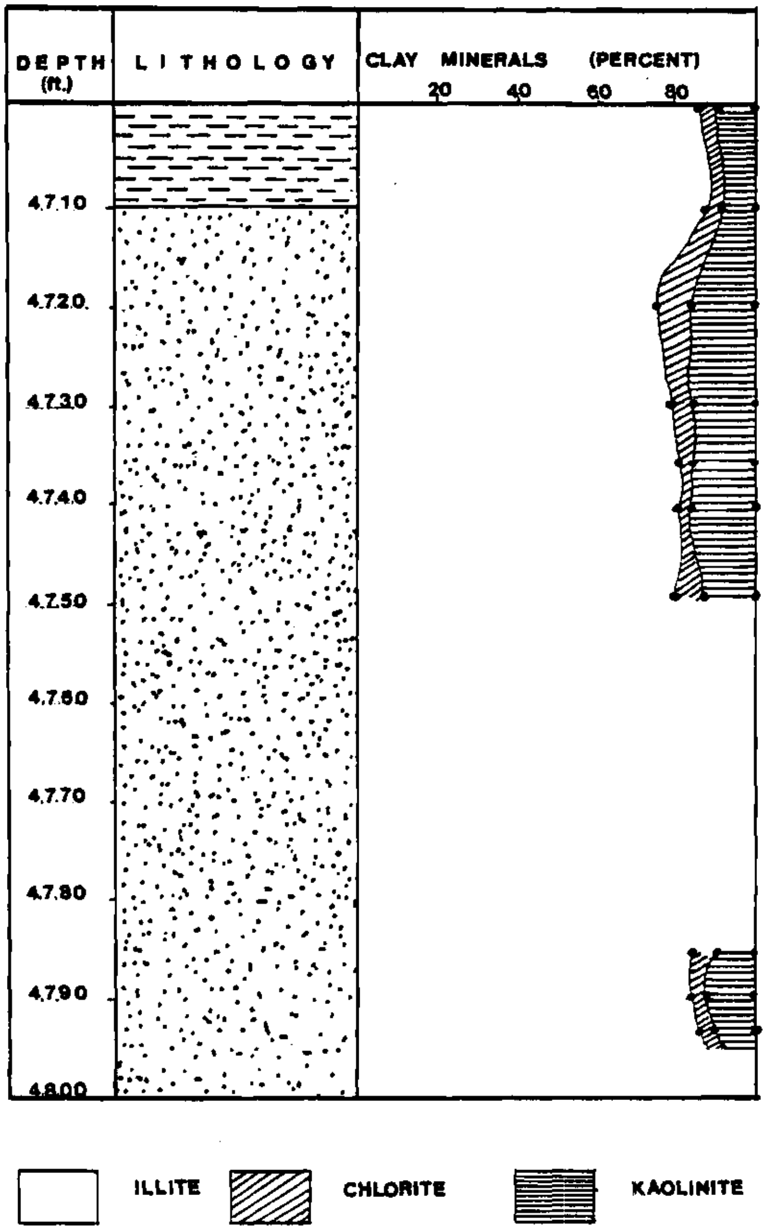

Figure 17. Percentage of Clay Minerals in Devonian Rocks of Citrus County, Florida.

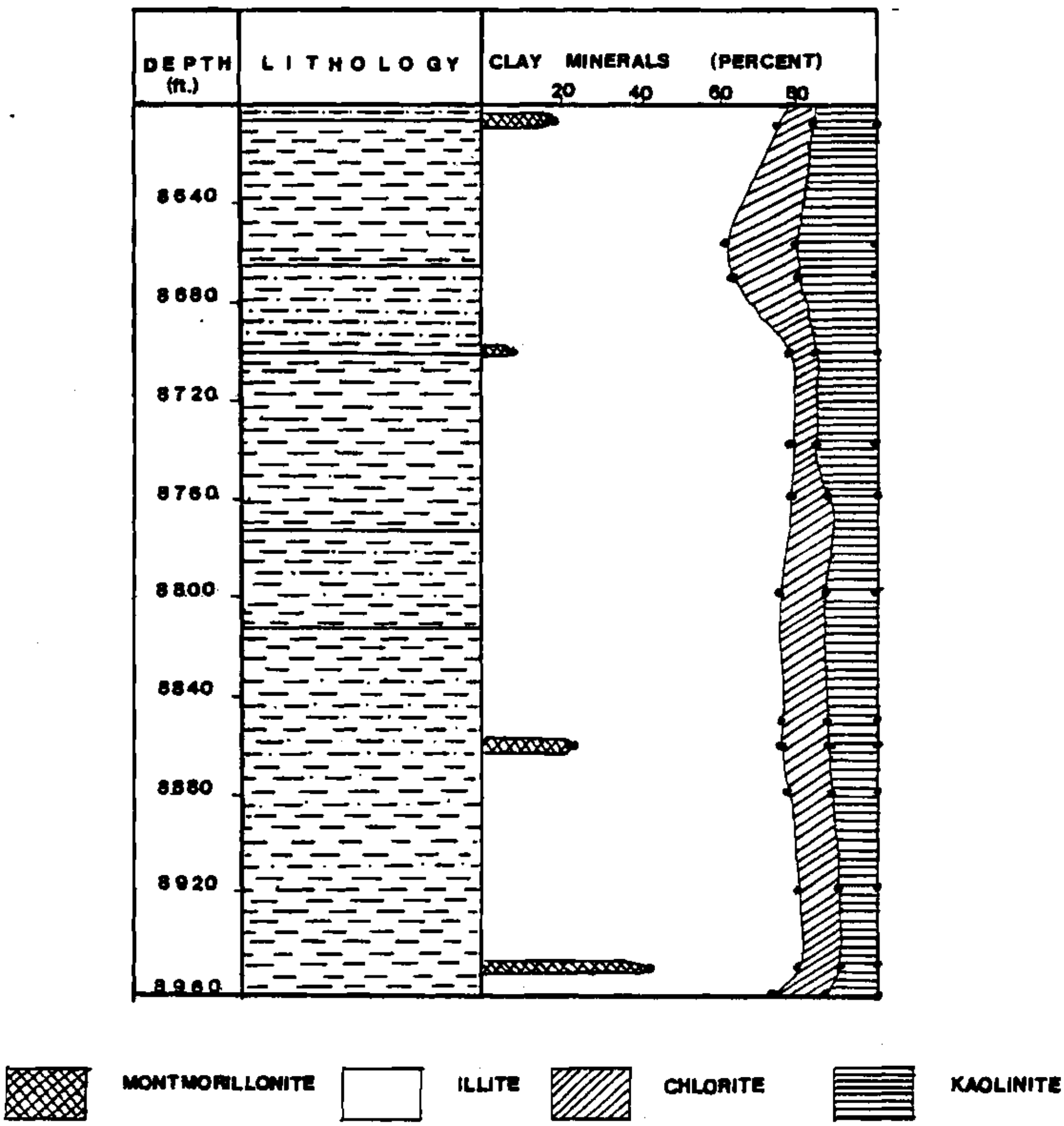

Figure 18. Percentage of Clay Minerals in Devonian Rocks of Jackson County, Florida.

Sample description: Red shale

Age: Devonian

Clay mineral composition: Montmorillonite traces. Illite ranges from 56 to 87 percent, averages 70 percent. Chlorite ranges from 4 to 11 percent, averages 7 percent. Kaolinite ranges from 0 to 23 percent averages 11 percent.

The percentage of clay minerals is shown in Figure 19.

Well location: Gulf County

Sample interval: 14,300 to 14,600 feet

Sample spacing: Variable

Sample description: Gray shale from 14,300 to 14,480 feet, and sandstone from 14,480 to 14,600 feet.

Age: Upper Paleozoic

Clay mineral composition: Illite ranges from 64 to 82 percent, averages 71 percent. Chlorite ranges from 3 to 20 percent, averages 13 percent. Kaolinite ranges from 13 to 21 percent, averages 16 percent.

The percentage of clay minerals is shown in Figure 20.

Well location: Columbia County

Sample interval: 2,770 to 2,900 feet

Sample spacing: Variable

Sample description: Limestone from 2,700 to 8,850 feet, and shale from 2,800 to 2,900 feet.

Age: Upper Paleozoic

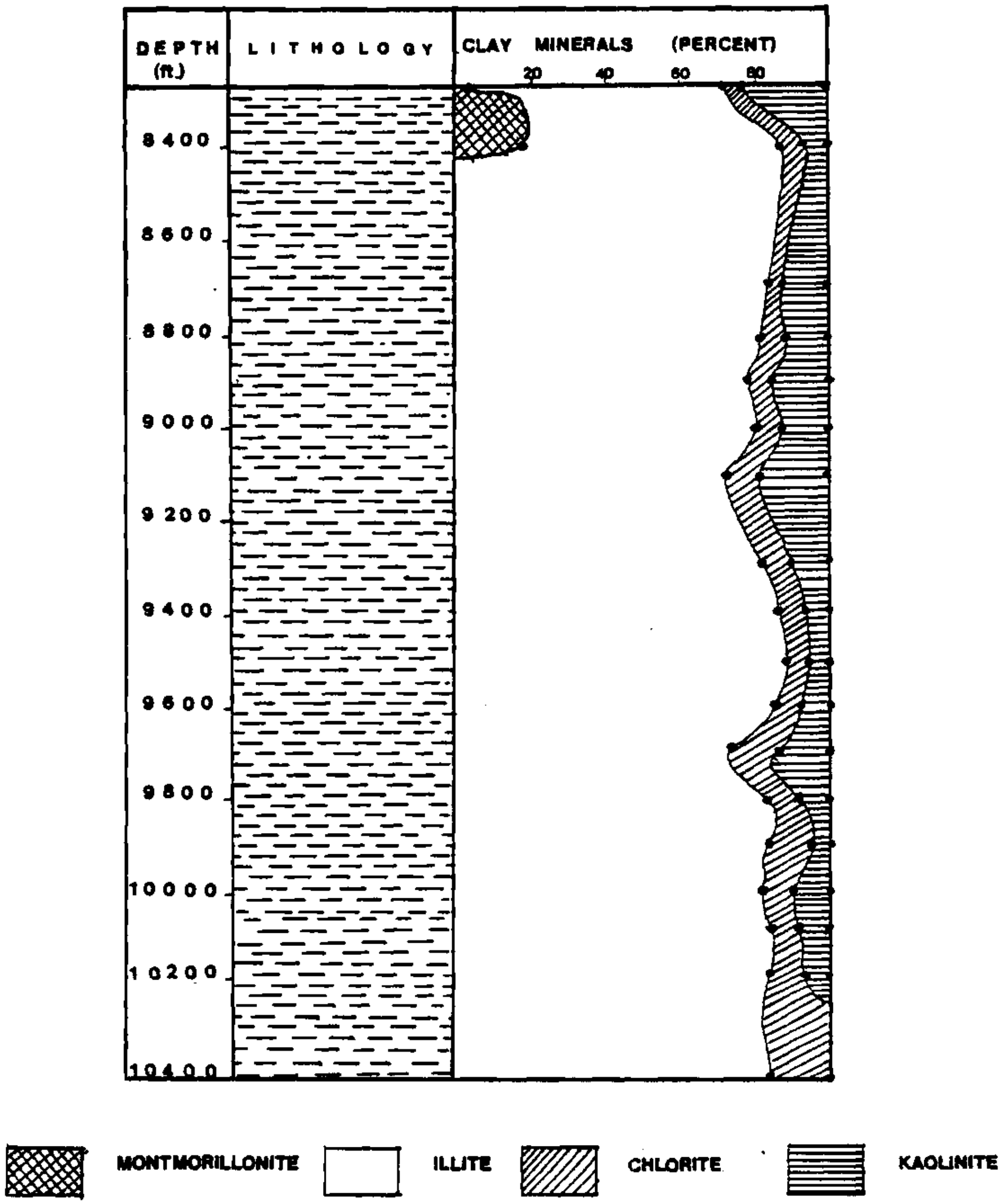

Figure 19. Percentage of Clay Minerals in Devonian Rocks of Leon County, Florida.

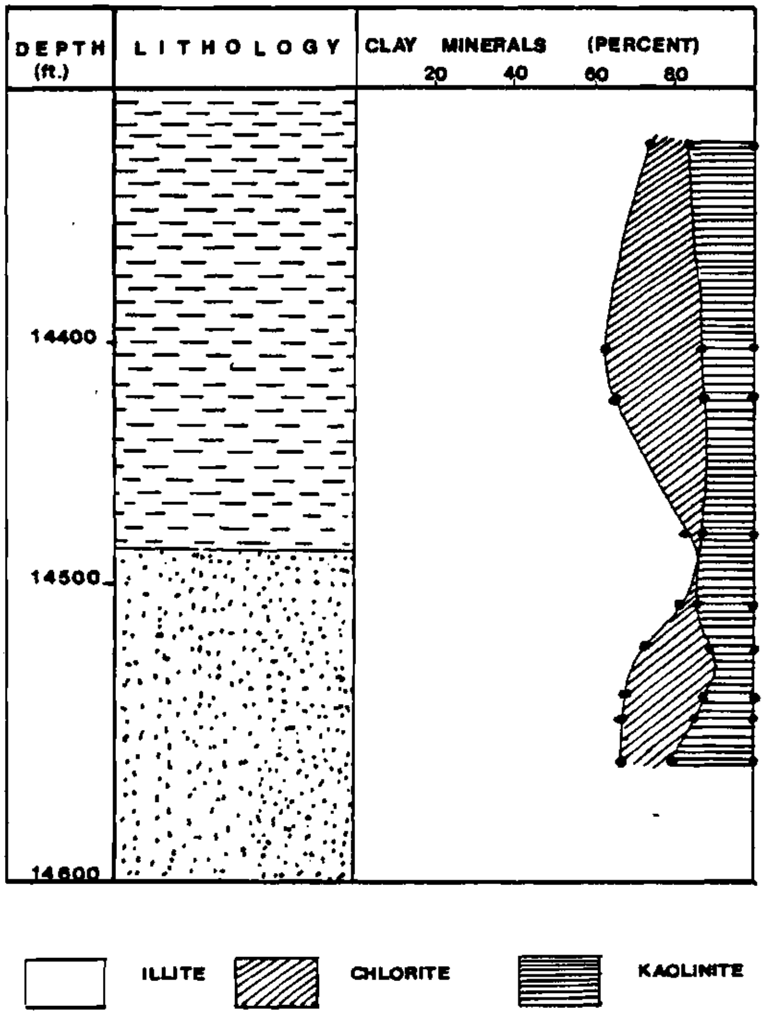

Figure 20. Percentage of Clay Minerals in Upper Paleozoic Rocks of Gulf County, Florida.

Clay mineral composition: Illite (plus montmorillonite (in one sample) ranges from 68 to 80 percent, averages 75 percent. Chlorite ranges from 0 to 10 percent, averages 3 percent. Kaolinite ranges from 10 to 32 percent, averages 23 percent.

The percentage of clay minerals is shown in Figure 21.

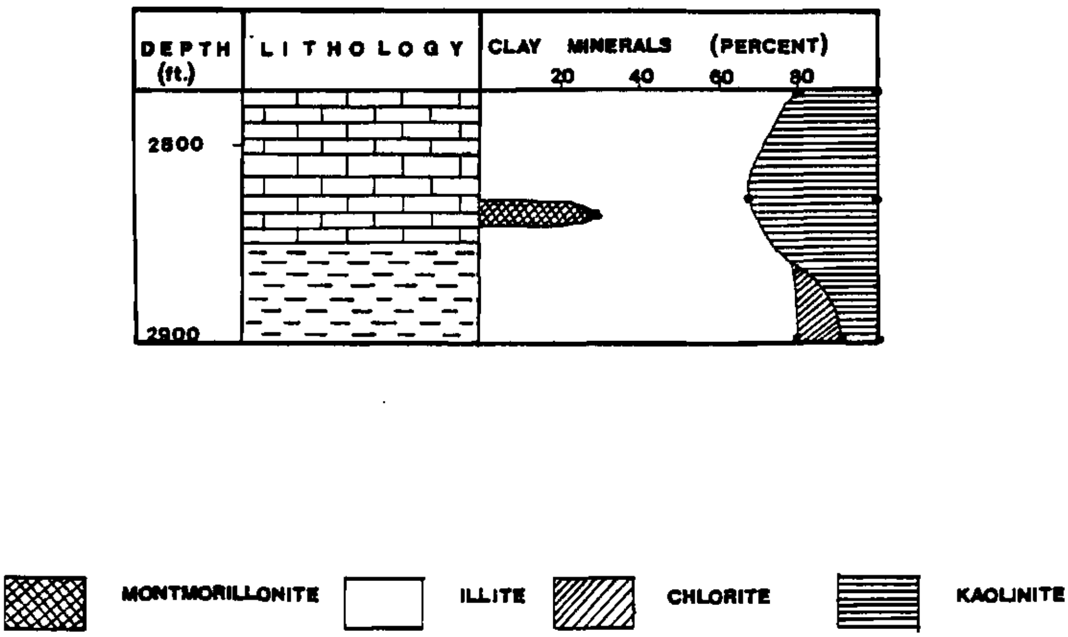

Figure 21. Percentage of Clay Minerals in Upper Paleozoic Rocks of Columbia County, Florida.

CHAPTER IV

CLAY MINERALS OF THE APPALACHIAN MOUNTAINS

Chowns (1972) described the lithology of Appalachian rocks in Northwest Georgia. There are complete sections of Paleozoic rocks. The outcrop region is shown in Figure 22. D. L. Rice (personal communication) worked on clay minerals of these Appalachian rocks. The description of rocks and clay minerals from Early to Late Paleozoic are described in the following pages.

Ordovician rocks are Chickamauga limestone and Sequatchie formations. The Chickamauga limestone is gray, bioturbated, clayey, and silty limestone, with abundant bryozoans and brachiopods. The illite content is 75 percent, and the chlorite content is 25 percent. Sequatchie formations are sandstone, siltstone, and shale. Gray sandstone contains illite 89 percent, and chlorite 11 percent. Gray shale with medium-grained sand contains about 93 percent illite, and about 7 percent chlorite. Sandy shale is dull red shale with medium sand; sandy shale has 94 percent illite, and 6 percent chlorite. Brachiopod calcarenite is extremely fossiliferous gray dolomitic medium to fine-grained sandstone. It contains 88 percent illite, and 12 percent chlorite. A mixture of fine-grained calcareous siltstone and green siltstone occurs in thin beds interlayered with gray sandstone.

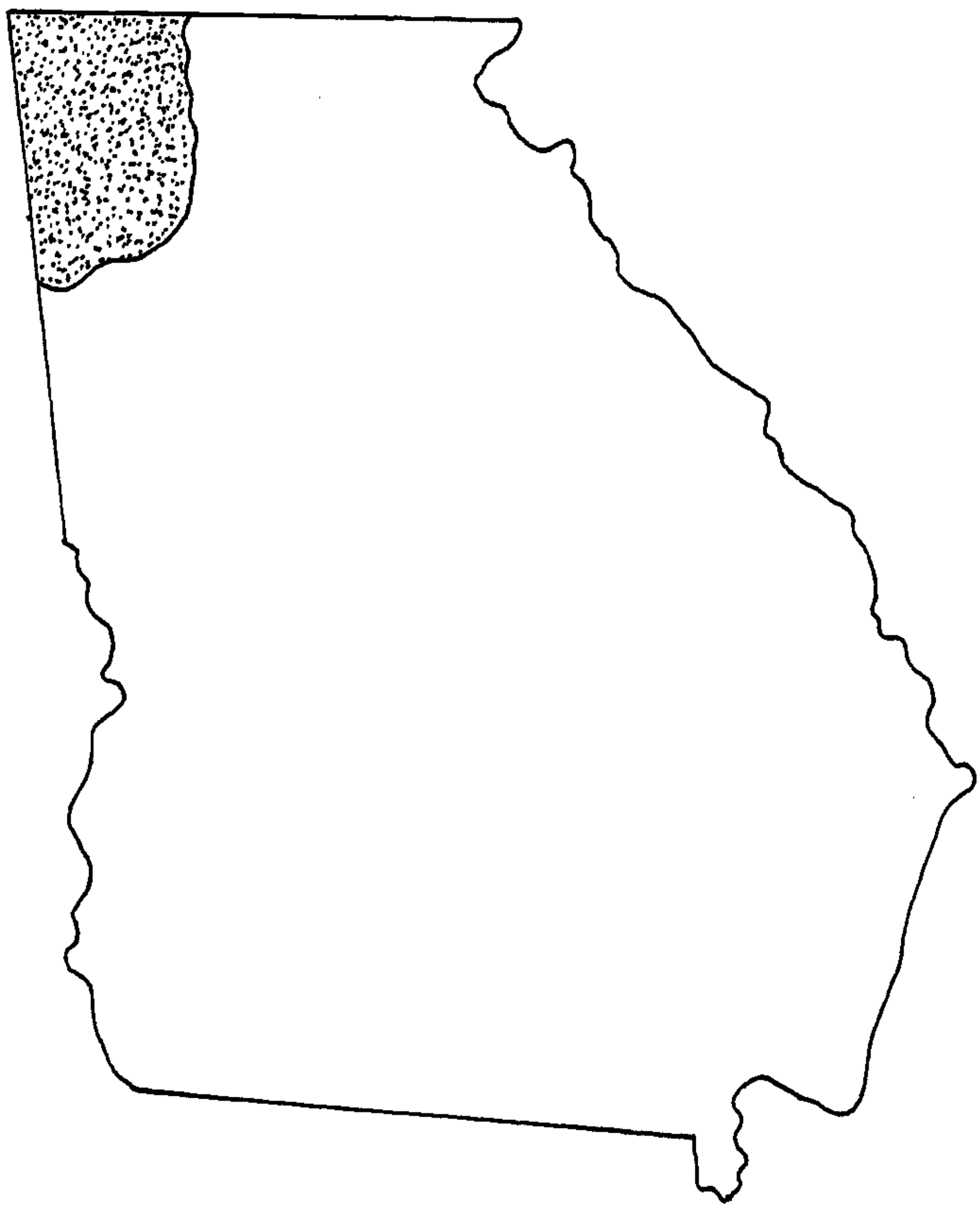

Figure 22. Area of Sampling of Appalachian Rocks of Northwest Georgia.

It contains 93 percent illite, and 7 percent chlorite.

Silurian rocks are sandstone, siltstone, and shales of Red Mountain formation. The descriptions of rock and clay content are in the following details.

- Fossiliferous silty sandstone: Gray, dirty sandstone with abundant brachiopods, bryozoans, and crinoids. The clay content is 92 percent illite and 8 percent chlorite.
- Calcareous shale: Red and gray mottled. The clay content is 92 percent illite and 8 percent chlorite.
- Hematitic sandstone: Red, sandy rock with powdery hematite replacing fossils. The clay content is 81 percent illite and 19 percent chlorite.
- Brachiopod sandstone: Gray calcareous sandstone with frequent brachiopods. The clay content is 91 percent illite and 9 percent chlorite.
- Sandstone: White, apparently well sorted, somewhat cross-bedded sandstone, some small muscovite flakes and an occasional pod of kaolinite. The clay content is 52 percent illite, 8 percent chlorite, and 40 percent kaolinite. This is the top of the Red Mountain formation.

The Devonian rock is Chattanooga shale. It is black in color and organically rich. The clay content is 94 percent illite and 6 percent chlorite.

The Mississippian rock is of Fort Payne, Monteagle, and Pennington formations. Fort Payne chert is the lower formation of the Mississippian rock; it is light gray with chert nodules. The clay content is 93 percent illite and 7 percent chlorite. Monteagle formation is in the Middle Mississippian. The rock is oolitic limestone, light gray, massive, and with a rough surface. The clay content is 93 percent illite and 7 percent chlorite. Pennington formation is on the top of the Mississippian. It is sandy shale, poorly laminated. The clay content is 82 percent illite, 4 percent chlorite, and 14 percent kaolinite. Percentages of clay minerals in these Appalachian rocks are shown in Figure 23.

C. E. Weaver (personal communication) also worked on clay minerals of Appalachian rock of Pennsylvania. Table 1 shows the clay mineral content of Appalachian rock of Pennsylvania. The clay mineral content of central Appalachian and southern Appalachian rock is similar.

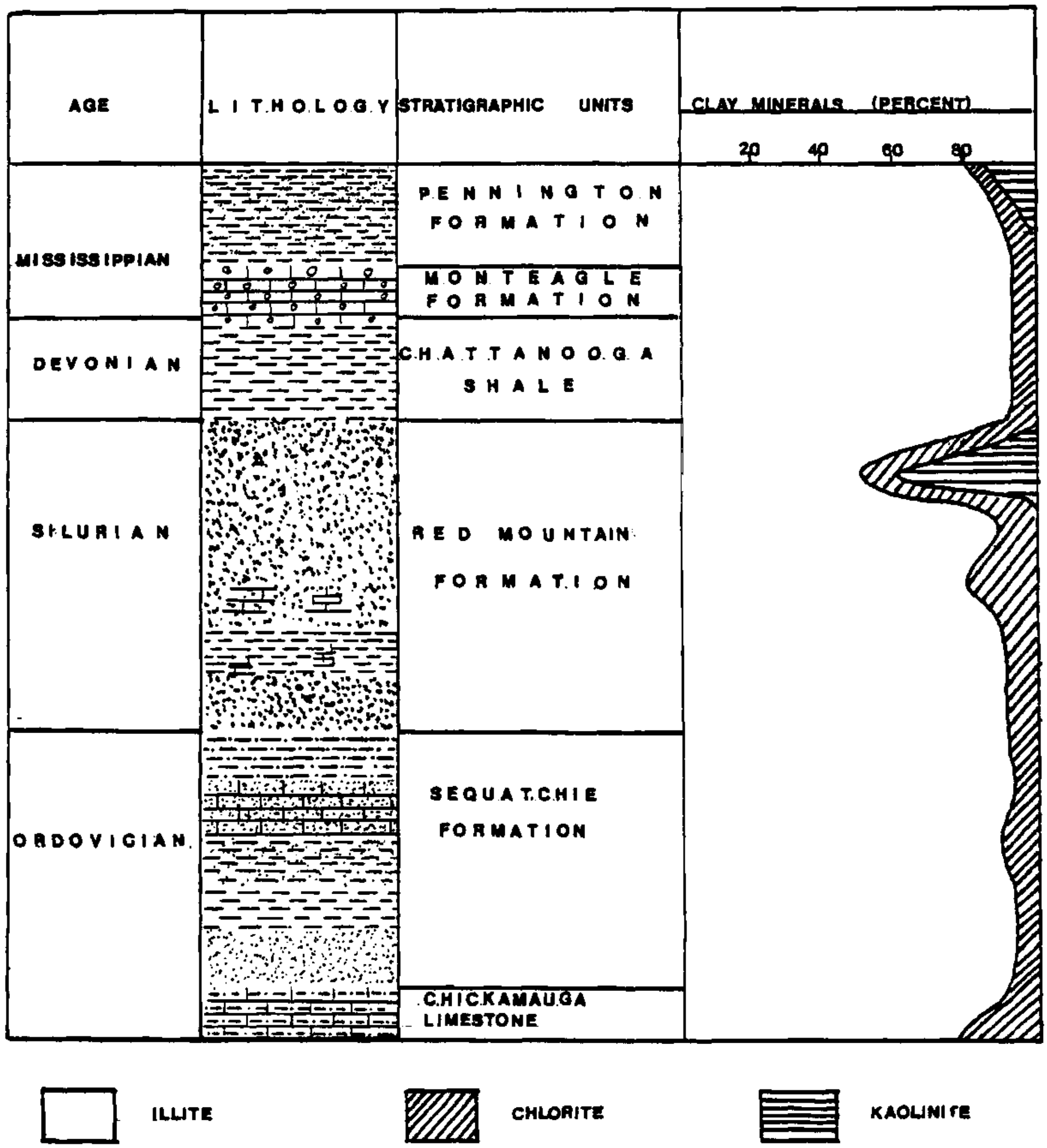

Figure 23. Percentage of Clay Minerals in Appalachian Rocks of Northwest Georgia.

Table 1.

Clay Mineral Content of Appalachian Rock of Pennsylvania

Age	Clay Mineral	Percent
Mississippian	Illite Chlorite Kaolinite	92 8 Trace
Devonian	Illite Chlorite	87 13
Silurian	Illite Chlorite	94 6
Ordovician	Illite Chlorite	91 9
Cambrian	Illite Chlorite	88 12

CHAPTER V

CLAY MINERALS OF PALEOZOIC ROCKS OF THE OUACHITA BELT

The Ouachita Belt is the area extending from southeastern Oklahoma and northeastern Texas to southwestern Texas, as shown in Figure 24. C. E. Weaver (personal communication) analyzed clay minerals of the Lower Paleozoic, determining the following data:

Age: Cambrian

Clay minerals composition: Illite ranges from 85 to 100 percent, averages 93 percent. Chlorite ranges from 5 to 15 percent.

Age: Ordovician

Clay mineral composition: Illite ranges from 75 to 100 percent, averages 95 percent. Chlorite ranges from 0 to 25 percent. Kaolinite traces.

Age: Silurian

Clay mineral composition: Illite ranges from 50 to 100 percent, averages 82 percent. Chlorite ranges from 0 to 50 percent, averages 18 percent.

Age: Devonian

Clay mineral composition: Illite ranges from 70 to

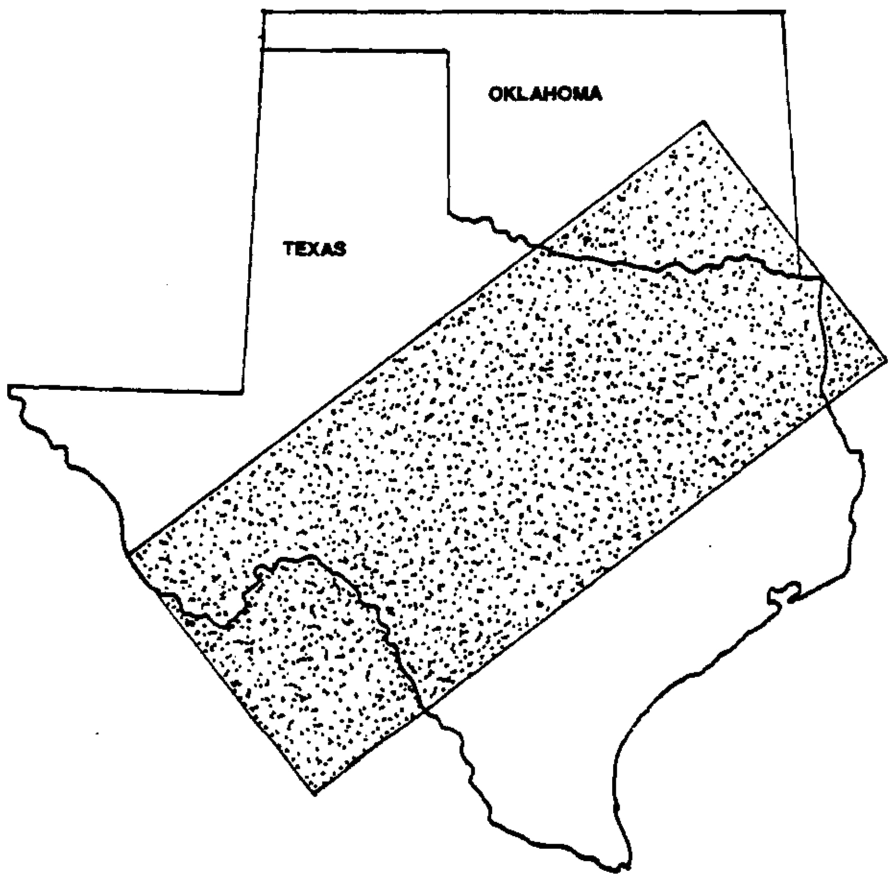

Figure 24. Location of Ouachita Belt (After Flawn, Goldstein, King, and Weaver, 1961).

100 percent, averages 93 percent. Chlorite ranges from 0 to 12 percent, averages 3 percent. Kaolinite ranges from 0 to 30 percent, averages 4 percent.

Upper Paleozoic clay minerals are described by Flawn, Goldstein, King, and Weaver (1961). Illite is highly abundant in these rocks. There is a minor amount of chlorite, averaging about 5 to 10 percent, and not over 40 percent. Kaolinite content is small and the mineral occurs scattered throughout the section. Stanley, Jackfork, John Valley, and Atoka are the rock formations present in southeastern Oklahoma. Their age is from Mississippian to Pennsylvanian. They contain 70 percent illite, 30 percent chlorite, and minor amounts of kaolinite and a mixed-layer illite-montmorillonite.

The Upper Mississippian Stanley formation is composed of shale, mostly gray, interbedded with dark gray argillaceous chloritic sandstone. Beds of siliceous shale identifiable over long distances are found at several horizons, and cone-in-cone concretions are abundant in places. Several beds of acidic vitric tuff are found near the base of the formation. The Stanley formation contains little kaolinite. Jackfork formation overlies Stanley formation and Mississippian rock. The lithologies are medium- to coarse-grained, hard sandstone, with intercalated shale. Sole marking are abundant in the sandstone. Also present are four beds of siliceous shale and one bed of maroon to green shale. Jackfork shales contain illite, a mixed-layer illite-montmorillonite, and minor amounts of kaolinite and chlorite. Johns Valley formation overlies Jackfork formation. Its age is Mississippian and Pennsylvanian. The lithologies are shale, light gray to tan and dark gray near the base, and thin beds of sandstone and limestone. Large erratic masses of limestone or shale of foreland facies are found near the base of the formation, and exotic boulders, pebbles, and granules occur at numerous horizons. Clay minerals in John Valley shales occur in about the same amounts as in Jackfork shales, but contain somewhat more kaolinite and chlorite. Kaolinite and chlorite appear in increasing amounts higher in the section. Atoka formation sits on the top of John Valley formation. The age is Pennsylvanian. The lithologies are shale, light gray, silty, micaceous, and flaky with interbedded fine- to coarse-grained, micaceous sandstone with very abundant sole markings. Thin siliceous shales are present at the base and in the lower part of the formation. Clay minerals in Atoka shales are similar to the John Valley shales but contain more chlorite and kaolinite. Table 2 is a summary of the clay mineral content of Paleozoic rock of Ouachita Belt.

Table 2.

Clay Mineral Content of Paleozoic Rock of Ouachita Belt

Age	Clay Mineral	Percent
Mississippian	Illite	70
	Chlorite	30
Devonian	Illite	93
	Chlorite	3
	Kaolinite	4
Silurian	Illite	82
	Chlorite	18
Ordovician	Illite	95
	Chlorite	5
	Kaolinite	Trace
Cambrian	Illite	93
	Chlorite	7

CHAPTER VI

CLAY MINERALS OF NORTHWESTERN AFRICA

Paleozoic rocks of Northwest Africa were drilled in the Polignac Basin of Sahara. The location of the basin is shown in Figure 25. The rocks of Polignac Basin are all Paleozoic in age. Figure 26 shows geologic setting of Polignac Basin. The Cambro-Ordovician rocks are exposed on the south of the basin. They lie on the Precambrian Hoggar Shield. The Cambro-Ordovician rocks show an irregular thickness from the south to the north, the thickness varies from 100 to 600 meters. The diagonal shading area of Figure 26 shows the Cambro-Ordovician outcrop. The Siluro-Devonian rocks lie on top of Cambro-Ordovician rocks. They have the maximum thickness at the east of the basin. Most of Siluro-Devonian rocks are covered by Carboniferous transgression. The stippled area of Figure 26 shows the Siluro-Devonian outcrop. Carboniferous rocks are exposed at the north and center of the basin. They lie on the top of Siluro-Devonian rocks. The rocks in the northern part show erosion effects. The maximum amount removed by erosion is about 1,400 meters. Carboniferous and Quaternary rocks are shown by white area of Figure 26. Dunoyer de Segonzac (1969) described the distribution of clay minerals of the Polignac Basin as summarized

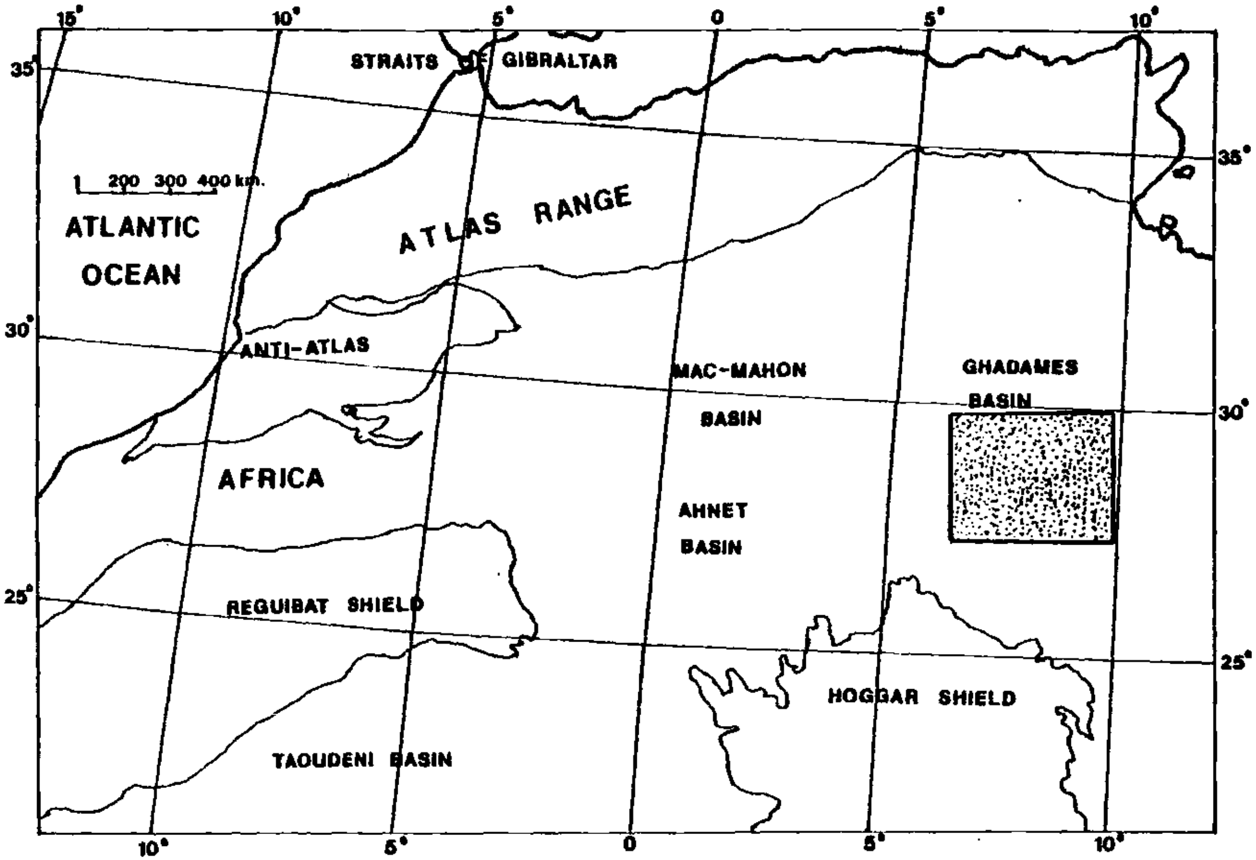

Figure 25. Location of Polignac Basin (stippled area), Northwest Africa. (After Dunoyer de Segonzac, 1969).

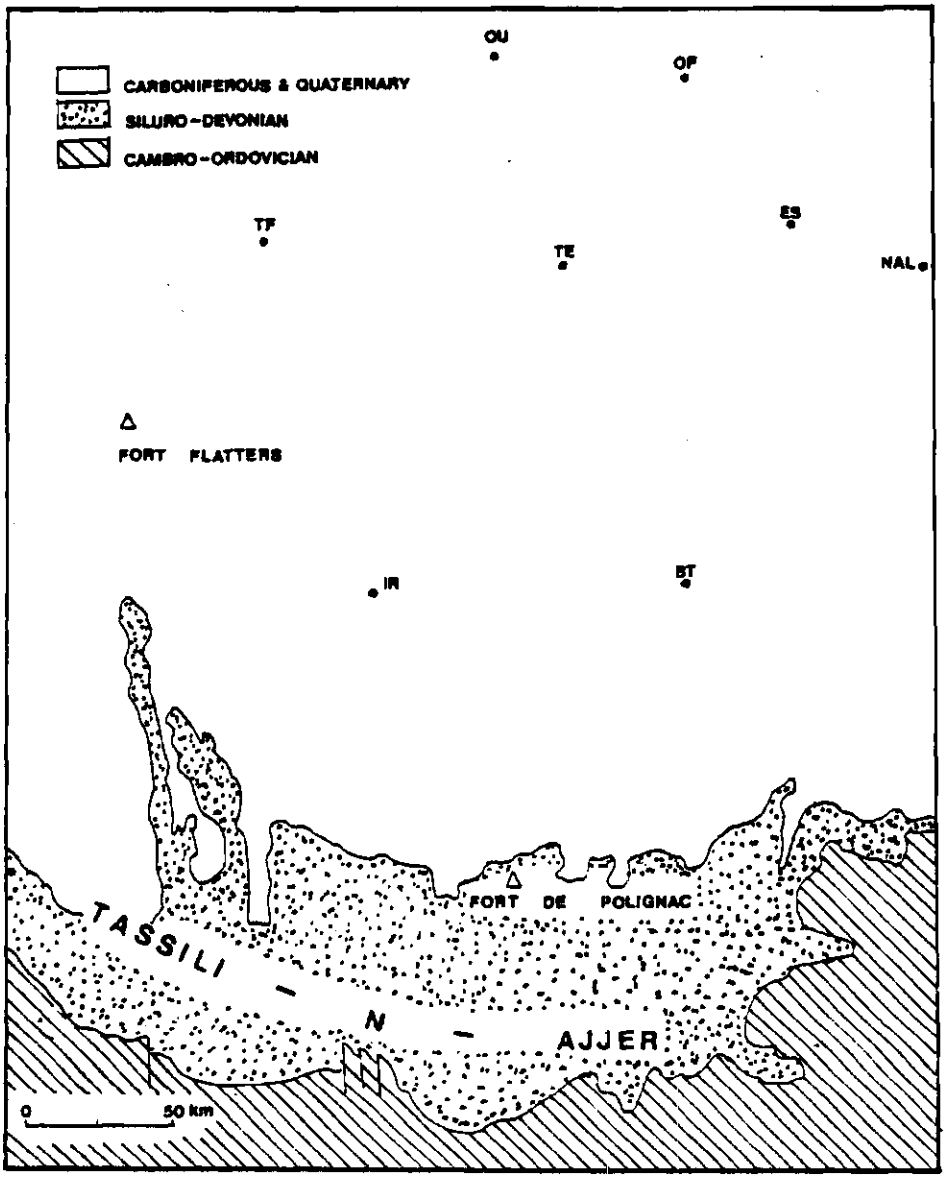

Figure 26. Geologic Setting of Polignac Basin. Abbreviations for well location: OU-Oudoume, OF-Ouan Fidjidjene, ES-Eslak, NAL-Nord Alrar, TF-Tifist, TE-Tesselit, IR-Irarraren, BT-Bourarhet. (After Dunoyer de Segonzac, 1969).

in the following pages.

Well location: Oudoume

Sample interval: 3,812 to 4,000 meters

Sample description: Alternation of sandstone and shale.

Age: Cambro-Ordovician

Clay mineral composition: Illite ranges from 68 to 70 percent, averages 69 percent. Chlorite ranges from 30 to 32 percent, averages 31 percent.

Sample interval: 3,062 to 3,750 meters

Sample description: Alternation of sand and shale between 3,062 to 3,500 meters, and shale from 3,500 to 3,750 meters.

Age: Silurian

Clay mineral composition: Illite plus mixed-layer ranges from 24 to 40 percent averages 32 percent. Chlorite ranges from 15 to 43 percent, averages 29 percent. Kaolinite ranges from 21 to 67 percent, averages 40 percent.

Sample intervals: 2,812 to 3,000 meters

Sample description: Mostly shales

Age: Devonian

Clay mineral composition: Illite plus mixed-layer ranges from 17 to 36 percent, averages 24 percent. Chlorite ranges from 13 to 20 percent, averages 17 percent. Kaolinite ranges from 46 to 67 percent, averages 60 percent.

Sample interval: 1,800 to 2,750 meters.

Sample description: Alternation of limestone, sandstone and shales from 1,800 to 2,562 meters, shale from 2,500 to 2,750 meters.

Age: Carboniferous

Clay mineral composition: Illite plus mixed-layer ranges from 27 to 69 percent, averages 47 percent. Chlorite ranges from 17 to 50 percent, averages 33 percent. Kaolinite ranges from 10 to 27 percent, averages 20 percent.

The percentage of clay minerals is shown in Figure 27.

Well location: Ouan Fidjidjene

Sample interval: 2,750 to 3,200 meters

Sample description: Alternation of shale, lime, sand and shaly sand.

Age: Devonian

Clay mineral composition: Illite plus mixed-layer ranges from 22 to 60 percent, averages 24 percent. Chlorite ranges from 20 to 40 percent, averages 29 percent. Kaolinite ranges from 20 to 42 percent, averages 37 percent.

Sample interval: 1,450 to 2,587 meters

Sample description: Alternation of sandstone, limestone and shale.

Age: Carboniferous

Clay mineral composition: Illite plus mixed-layer ranges from 30 to 79 percent, averages 55 percent. Chlorite ranges from 10 to 38 percent, averages 22 percent. Kaolinite ranges from 11 to 32 percent, averages 23 percent.

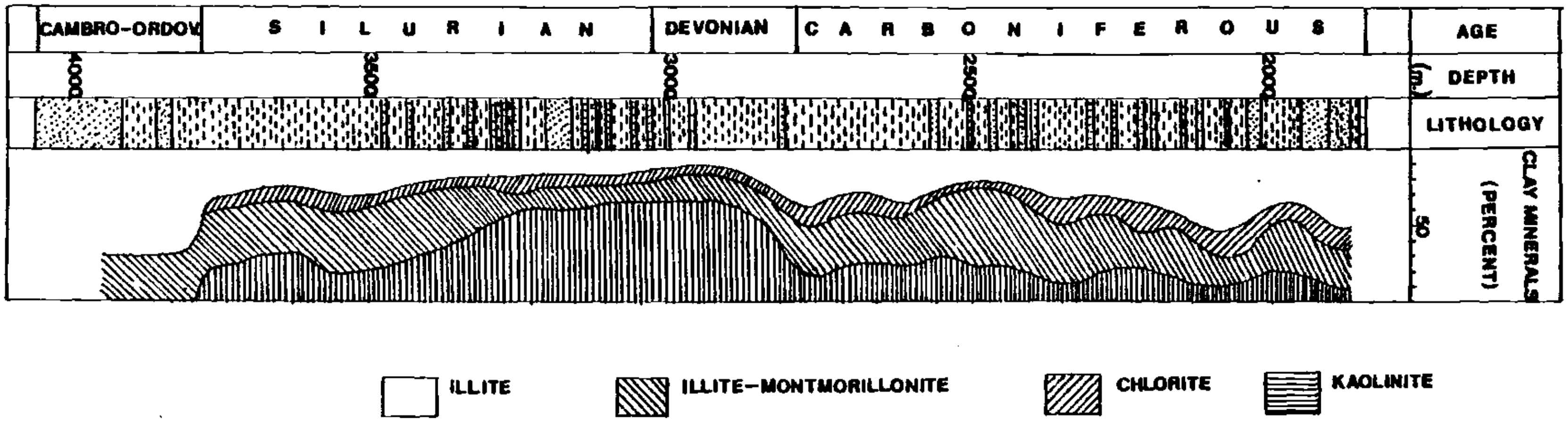

Figure 27. Percentage of Clay Minerals of Oudoume, Polignac Basin. (After Dunoyer de Segonzac, 1969).

The percentage of clay minerals is shown in Figure 28.

Well location: Ouine Eslak

Sample interval: 3,187 to 3,500 meters

Sample description: Shale at the top sand at the middle, and shale at the bottom.

Age: Cambro-Ordovician

Clay mineral composition: Illite plus mixed-layer ranges from 33 to 78 percent, averages 57 percent. Chlorite ranges from 21 to 31 percent, averages 25 percent. Kaolinite ranges from 2 to 36 percent, averages 17 percent.

Sample interval: 3,000 to 3,125 meters

Sample description: Shale

Age: Silurian

Clay mineral composition: Illite plus mixed-layer ranges from 30 to 36 percent, averages 32 percent. Chlorite ranges from 28 to 40 percent, averages 33 percent. Kaolinite ranges from 24 to 42 percent, averages 35 percent.

Sample interval: 2,500 to 2,937 meters

Sample description: Alternation of sandstone, limestone and shale.

Age: Devonian

Clay mineral composition: Illite plus mixed-layer ranges from 32 to 37 percent, averages 35 percent. Chlorite ranges from 26 to 31 percent, averages 28 percent. Kaolinite ranges from 31 to 43 percent, averages 37 percent.

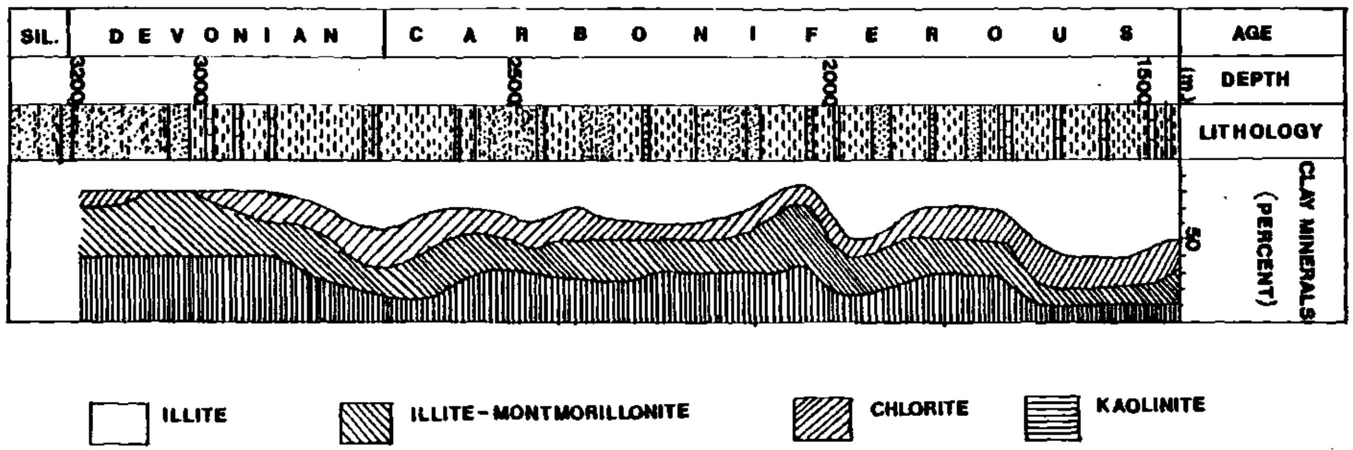

Figure 28. Percentage of Clay Minerals of Ouan, Polignac Basin.
(After Dunoyer de Segonzac, 1969).

Sample interval: 1,500 to 2,437 meters.

Sample description: Alternation of sand and shale from 1,500 to 2,125 meters, shale from 2,125 to 2,437 meters.

Age: Carboniferous

Clay mineral composition: Illite plus mixed-layer ranges from 47 to 60 percent, averages 52 percent. Chlorite ranges from 20 to 26 percent, averages 23 percent. Kaolinite ranges from 16 to 32 percent, averages 25 percent.

The percentage of clay minerals is shown in Figure 29.

Well location: Nord Alrar

Sample interval: 2,400 to 2,750 meters

Sample description: Alternation of sandstone, limestone, and shale.

Age: Devonian

Clay mineral composition: Illite plus mixed-layer ranges from 28 to 59 percent, averages 39 percent. Chlorite ranges from 30 to 46 percent, averages 38 percent. Kaolinite ranges from 11 to 28 percent, averages 23 percent.

Sample interval: 1,350 to 2,350 meters

Sample description: Alternation of sandstone and shale.

Age: Carboniferous

Clay mineral composition: Illite plus mixed-layer ranges from 36 to 79 percent, averages 54 percent. Chlorite ranges from 11 to 39 percent, averages 27 percent. Kaolinite

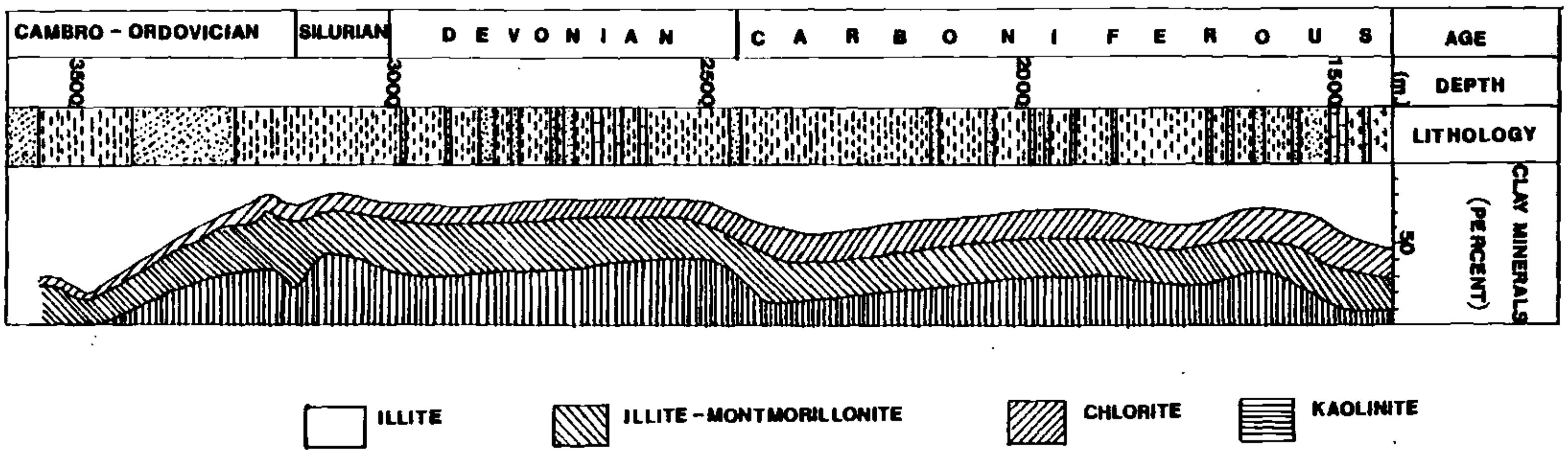

Figure 29. Percentage of Clay Minerals of Ouine Eslak, Polignac Basin. (After Dunoyer de Segonzac, 1969).

ranges from 10 to 20 percent, averages 19 percent.

The percentage of clay minerals is shown in Figure 30.

Well location: Oued Tifist

Sample interval: 1,650 to 2,250

Sample description: Sandstones and shales

Age: Ordo-Silurian

Clay mineral composition: Illite plus mixed-layer ranges from 74 to 88 percent, averages 81 percent. Chlorite ranges from 10 to 17 percent, averages 13 percent. Kaolinite ranges from 4 to 14 percent, averages 6 percent.

Sample interval: 1,550 to 1,600 meters

Sample description: Sandstone

Age: Devonian

Clay mineral composition: Illite plus mixed-layer ranges from 90 to 91 percent, averages 90 percent. Chlorite ranges from 9 to 10 percent, averages 10 percent.

The percentages of clay minerals is shown in Figure 31.

Well location: Tesselit

Sample interval: 2,272 to 2,800 meters

Sample description: Sandstone from 2,272 to 2,439 meters, shale from 2,439 to 2,800 meters.

Age: Ordo-Silurian

Clay mineral composition: Illite plus mixed-layer ranges from 70 to 80 percent, averages 73 percent. Chlorite

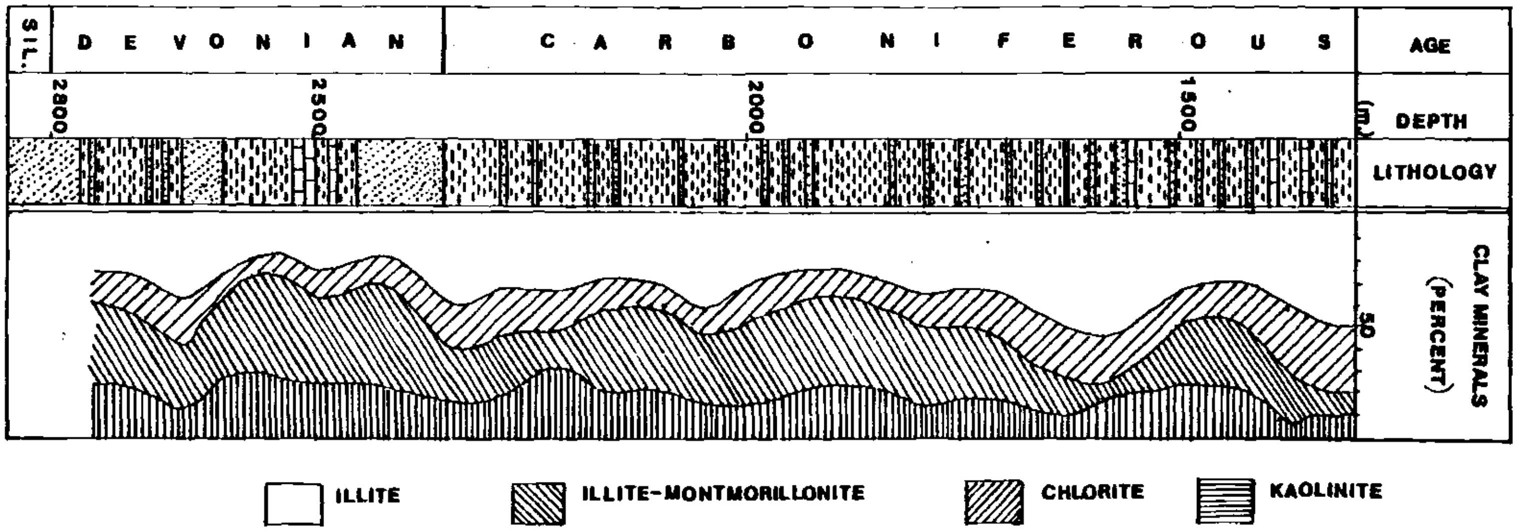

Figure 30. Percentage of Clay Minerals of Nord Alrar, Polignac Basin. (After Dunoyer de Segonzac, 1969).

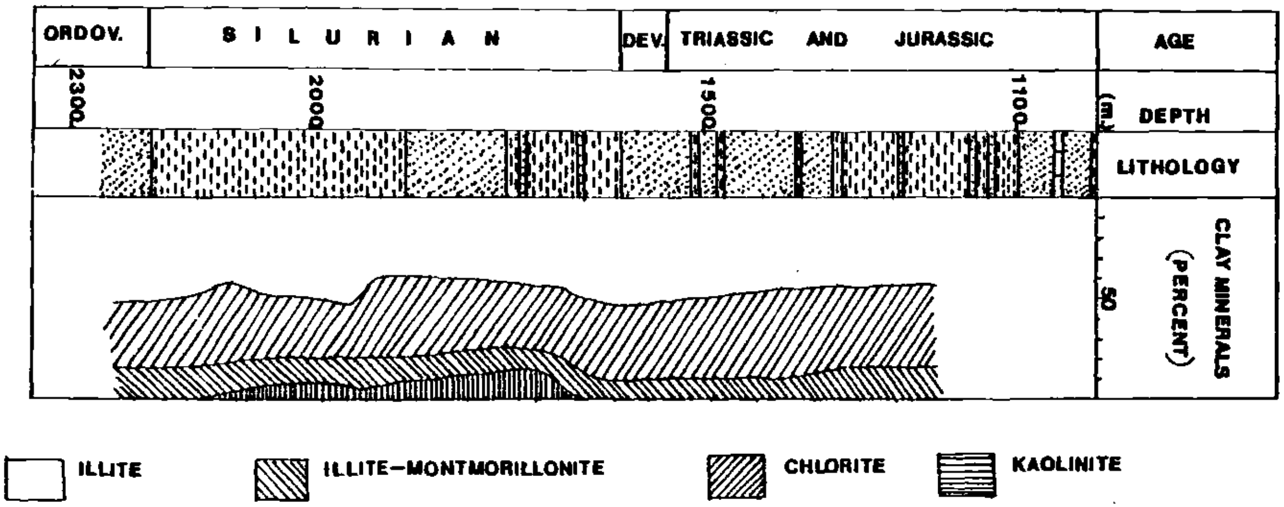

Figure 31. Percentage of Clay Minerals of Oued Tifist, Polignac, Basin. (After Dunoyer de Segonzac, 1969).

ranges from 10 to 22 percent, averages 14 percent. Kaolinite ranges from 1 to 19 percent, averages 13 percent.

Sample interval: 2,062 to 2,250 meters

Sample description: Alternation of sandstone, limestone and shales.

Age: Devonian

Clay mineral composition: Illite plus mixed-layer ranges from 69 to 90 percent, averages 82 percent. Chlorite ranges from 10 to 19 percent, averages 14 percent. Kaolinite ranges from 0 to 12 percent, averages 4 percent.

Sample interval: 1,000 to 2,000 meters

Sample description: Alternation of sandstone, limestone and shale.

Age: Carboniferous

Clay mineral composition: Illite plus mixed-layer ranges from 58 to 100 percent, averages 78 percent. Chlorite ranges from 0 to 29 percent, averages 15 percent. Kaolinite ranges from 0 to 15 percent, averages 7 percent.

The percentage of clay minerals is shown in Figure 32.

Well location: Irraren

Sample interval: 1,937 to 2,125 meters

Sample description: Sandstone, shale

Age: Ordovician

Clay mineral composition: Illite plus mixed-layer ranges from 60 to 85 percent, averages 68 percent. Chlorite

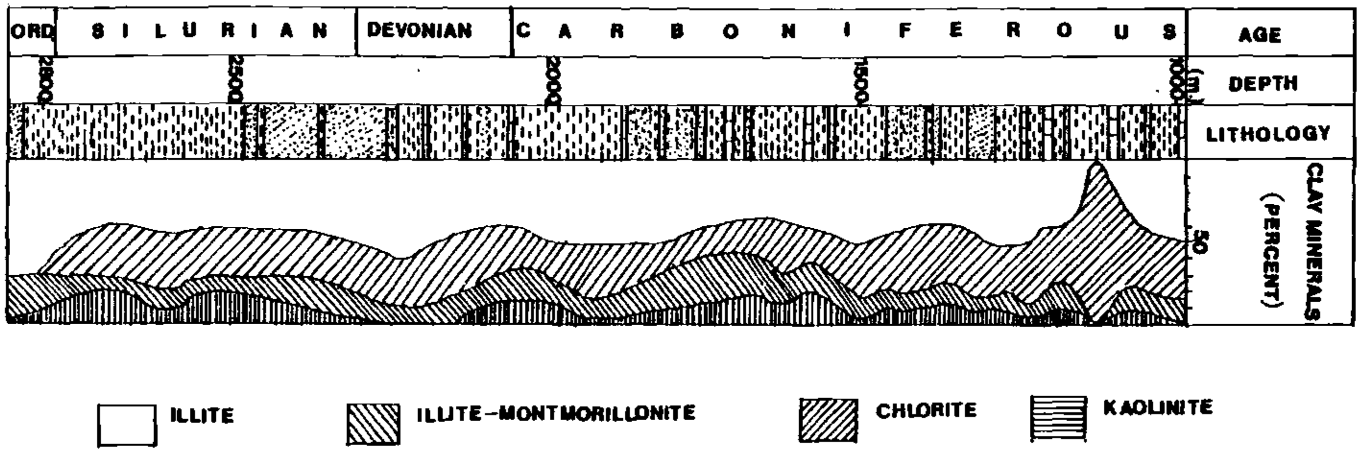

Figure 32. Percentage of Clay Minerals of Tesselit, Polignac Basin. (After Dunoyer de Segonzac, 1969).

ranges from 5 to 30 percent, averages 15 percent. Kaolinite ranges from 10 to 27 percent, averages 17 percent.

Sample interval: 1,457 to 1,875 meters

Sample description: Alternation of sandstone and shale from 1,457 to 1,562 meters, shale from 1,562 to 1,875 meters.

Age: Silurian

Clay mineral composition: Illite plus mixed-layer ranges from 65 to 81 percent, averages 72 percent. Chlorite ranges from 8 to 16 percent, averages 11 percent. Kaolinite ranges from 11 to 27 percent, averages 17 percent.

Sample interval: 750 to 1,375 meters

Sample description: Alternation of sandstone, limestone and shale.

Age: Devonian

Clay mineral composition: Illite plus mixed-layer ranges from 68 to 78 percent, averages 74 percent. Chlorite ranges from 2 to 11 percent, averages 7 percent. Kaolinite ranges from 8 to 25 percent, averages 19 percent.

Sample interval: 100 to 637 meters

Sample description: Alternation of sandstone and shale

Age: Carboniferous

Clay mineral composition: Illite plus mixed-layer ranges from 71 to 83 percent, averages 78 percent. Chlorite ranges from 10 to 27 percent, averages 17 percent. Kaolinite ranges from 0 to 10 percent, averages 4 percent.

The percentage of clay minerals is shown in Figure 33.

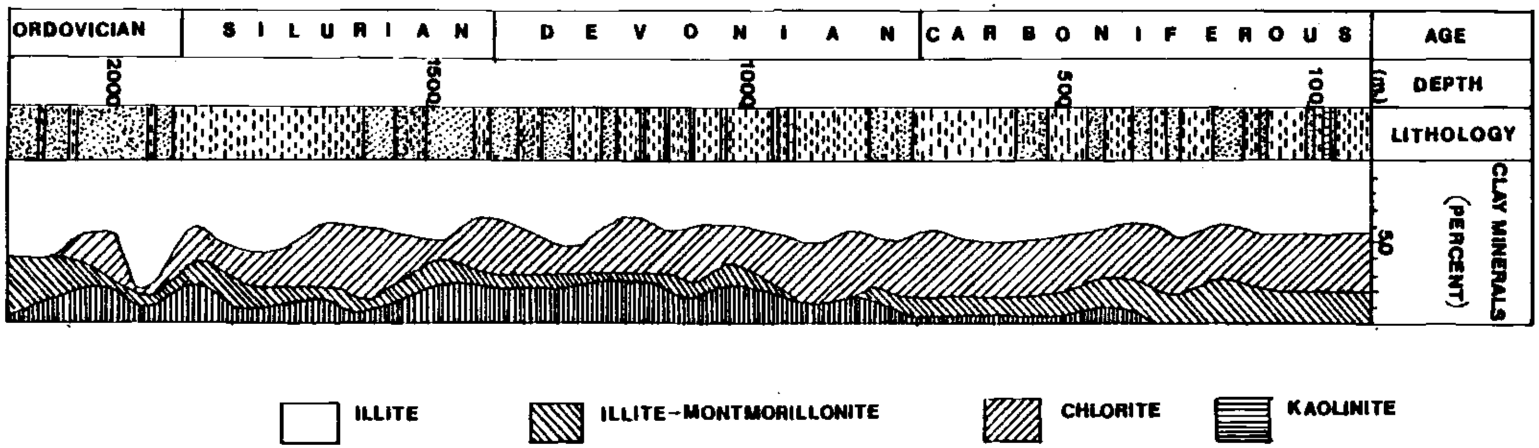

Figure 33. Percentage of Clay Minerals of Irraren, Polignac Basin. (After Dunoyer de Segonzac, 1969).

Well location: Bourarhet

Sample interval: 2,125 to 2,300 meters

Sample description: Shale from 2,125 to 2,187 meters, sandstone from 2,187 to 2,300 meters

Age: Ordovician

Clay mineral composition: Illite plus mixed-layer ranges from 56 to 67 percent, averages 63 percent. Chlorite ranges from 28 to 33 percent, averages 29 percent. Kaolinite ranges from 5 to 16 percent, averages 7 percent.

Sample interval: 1,562 to 2,062 meters

Sample description: Alternation of sandstone and shale from 1,562 to 1,625 meters, shale from 1,625 to 2,062 meters.

Age: Silurian

Clay mineral composition: Illite plus mixed-layer ranges from 19 to 48 percent, averages 34 percent. Chlorite ranges from 29 to 41 percent averages 34 percent. Kaolinite ranges from 24 to 40 percent, averages 32 percent.

Sample interval: 1,062 to 1,500 meters

Sample description: Alternation of sand and shale.

Age: Devonian

Clay mineral composition: Illite plus mixed-layer ranges from 22 to 51 percent, averages 38 percent. Chlorite ranges from 28 to 46 percent, averages 35 percent. Kaolinite ranges from 23 to 31 percent, averages 27 percent.

Sample interval: 450 to 1,000 meters

Sample description: Alternation of sand and shale.

Age: Carboniferous

Clay mineral composition: Illite plus mixed-layer ranges from 28 to 71 percent, averages 48 percent. Chlorite ranges from 17 to 47 percent, averages 31 percent. Kaolinite ranges from 12 to 30 percent, averages 21 percent.

The percentage of clay mineral is shown in Figure 34.

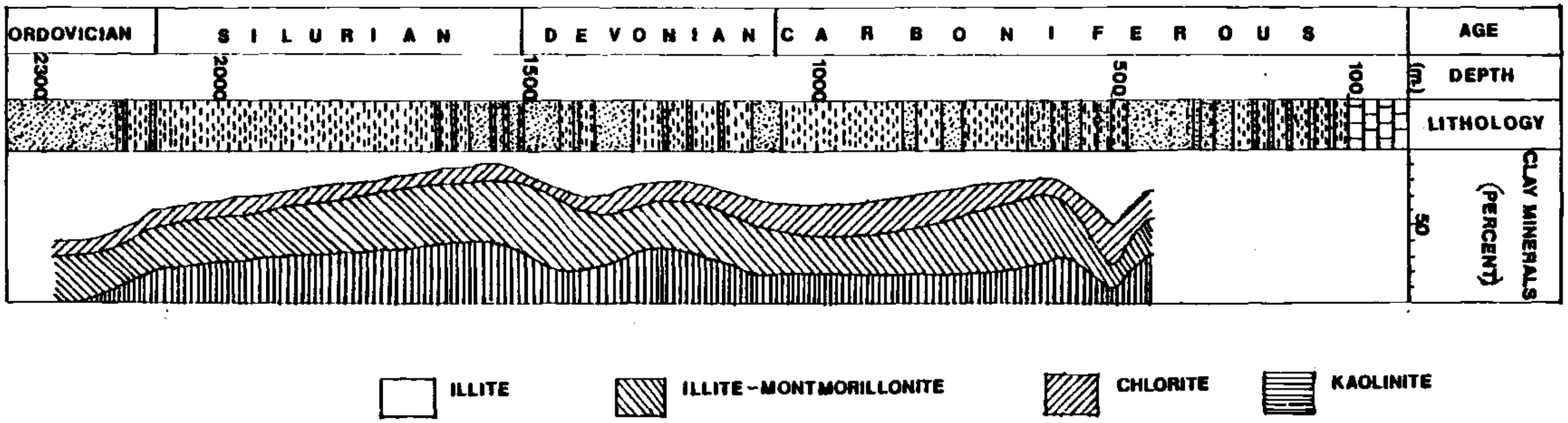

Figure 34. Percentage of Clay Minerals of Bourarhet, Polignac Basin.
(After Dunoyer de Segonzac, 1969).

CHAPTER VII

CLAY MINERAL COMPARISON OF FLORIDA, APPALACHIAN MOUNTAIN, AND OUACHITA BELT

The Cambrian rock of Florida and the Ouachita Belt does not have the same kind and amount of clay minerals. Comparing clay mineral variation from Figures 12, and 13 and data on page 44, the illite content of the Ouachita Belt is slightly greater than that of Florida. Chlorite content in the Ouachita Belt is about half that of Florida. Kaolinite does not appear in the Ouachita Belt but is present in Cambrian rock of Florida.

The Ordovician rock of the Ouachita Belt has nearly the same clay suite as the Appalachian rock. From the data on pages 44 and 38, illite is most abundant with 75 to 100 percent, and chlorite has 0 to 25 percent. The Ordovician rocks of Florida do not have the same clay suite as the Ouachita and Appalachian. From the data on pages 44 and 38 and Figures 14 and 15, the chlorite content of the Ouachita and Appalachian is less than that of Florida. Kaolinite does not appear in the Appalachian and only as traces in the Ouachita, but is present in some of the Ordovician rocks of Florida.

The Silurian clays of the Ouachita Belt have about the same composition as the Appalachian (data on pages 40 and 44). Kaolinite is absent except in one case - 40%.

The Devonian rocks of Florida do not have the same clay suite as the Chattanooga shale of the Appalachian Mountains. Kaolinite does not appear in Chattanooga shale, but is present in Devonian rocks of Florida. The Chattanooga shale has about the same amount of illite as the Devonian of the Ouachita area, approximately 93 percent. The chlorite content of the Ouachita is less than Chattanooga shale (3 percent). Kaolinite does not appear in Chattanooga shale, but is present in Devonian rocks of the Ouachita area. The Devonian clays of Florida, Figures 16, 17, 18, and 19, do not have the same composition as clays in Devonian rocks of the Ouachita (data on page 44). The illite content of Florida is less than that of the Ouachita area. The chlorite content of Florida is greater than that of the Ouachita area. Kaolinite content of Florida is greater than that of the Ouachita area. Montmorillonite does not appear in Ouachita area, but is present in some of the Devonian rocks of Florida.

The Mississippian clays of Appalachian Mountains do not have exactly the same composition as clay in the Ouachita area. Illite content of the Appalachian clay is considerably greater than that of the Ouachita area. Chlorite content of the Appalachian clay is much less than that of the Ouachita area. Kaolinite has the same variation in the Upper Mississippian in both regions (data on pages 41 and 46).

The Upper Paleozoic clays of Florida do not have the same clay suite as clays in the Appalachian and Ouachita areas. Illite content of Florida is less than that of the Appalachian but quite similar to that of the Ouachita area. Chlorite content of Florida is in between that of the Appalachian and Ouachita areas. Kaolinite is more common and more abundant than that of the Appalachian and Ouachita areas.

This is the comparison of clay suite of Florida, and the Appalachian and Ouachita areas. The kinds and amounts of clay minerals of the Appalachian and Ouachita areas are similar, but are different for Florida, except perhaps in the Upper Paleozoic. In the Early Paleozoic, Appalachian clays appear to have been derived from the same source material as the Ouachita clays.

CHAPTER VIII

CLAY MINERAL CORRELATION OF EASTERN NORTH AMERICA, AND NORTHWESTERN AFRICA

In Ordovician, illite content of Florida is similar to illite plus mixed layer of northwestern Africa. Chlorite content of Florida is also similar to chlorite of northwestern Africa. Kaolinite of northwestern Africa is greater than that of Florida. The kind and amount of clay minerals of Appalachian and Ouachita areas are different from Florida and Northwestern Africa. (Table 3)

In Silurian, illite content of Appalachian and Ouachita areas are greater than illite plus mixed-layer of Northwestern Africa. Chlorite and kaolinite content of Appalachian and Ouachita areas are less than that of northwestern Africa. In Devonian, the clay mineral content of Florida is different from northwestern Africa, but they show the same relative abundances. Kaolinite is present in greater amounts than chlorite, while chlorite is present in greater amounts than kaolinite from Cambrian to the Ordovician periods. Illite content of Appalachian and Ouachita areas are greater than that of Florida and northwestern Africa. Chlorite and kaolinite of Appalachian and Ouachita areas are less than that of Florida and northwestern Africa. In Carboniferous, illite

Table 3. Percentage of Clay Minerals of Eastern North America and Northwestern Africa

Age/Place	Appalachian	Ouachita	Florida	Northwestern Africa
Cambrian	-	Illite 93% Chlorite 7% Kaolinite -	Illite 81% Chlorite 13% Kaolinite 5%	-
Ordovician	Illite 89% Chlorite 11% Kaolinite -	Illite 95% Chlorite 5% Kaolinite Trace	Illite 70% Chlorite 24% Kaolinite 3% Montmorillonite 3%	Illite & Mixed Layer 64% Chlorite 25% Kaolinite 9%
Silurian	Illite 83% Chlorite 11% Kaolinite 6%	Illite 81% Chlorite 19% Kaolinite -	-	Illite & Mixed Layer 54% Chlorite 22% Kaolinite 27%
Devonian	Illite 94% Chlorite 6% Kaolinite -	Illite 93% Chlorite 3% Kaolinite 4%	Illite 78% Chlorite 7% Kaolinite 13% Montmorillonite 2%	Illite & Mixed Layer 52% Chlorite 22% Kaolinite 26%
Carboniferous	Illite 89% Chlorite 6% Kaolinite 5%	Illite 70% Chlorite 30% Kaolinite Trace	Illite 72% Chlorite 11% Kaolinite 19%	Illite & Mixed Layer 59% Chlorite 24% Kaolinite 17%

and chlorite content of Florida are not the same as northwestern Africa. Kaolinite content of Florida and northwestern Africa is similar. The kind and amount of clay minerals of Appalachian and Ouachita areas are different from Florida and northwestern Africa.

Table 4 shows an average of the percentages of clay minerals of Paleozoic rocks (with each geologic period given equal weight) of eastern North America and northwestern Africa. Table 5 shows ratio of other clays to kaolinite.

Weaver (personal communication) states that kaolinite is considerably more abundant in the Late Paleozoic sediments of Africa and South America than in North America and Europe. A mixed-layer illite-montmorillonite in sediments can transform to illite by diagenetic process if the sediments are metamorphosed (Weaver and Pollard, 1973). Illite of Northeastern America may derive from mixed-layer illite-montmorillonite. Barnett (1975) also described the metamorphism in for Paleozoic sedimentary rocks of Florida. This is the reason correlation of mixed-layer plus illite of northwestern Africa to illite content of North America.

Table 4. Average Percentages of Clay Minerals of Paleozoic Rocks of Eastern North America and Northwestern Africa

Clay Mineral/Place	Appalachian	Ouachita	Florida	Northwestern Africa
Illite	88%	86%	76%	+ Mixed Layer 57%
Chlorite	9%	13%	14%	23%
Kaolinite	3%	1%	10%	19%

Table 5. Ratio of Other Clays to Kaolinite

Clay / Kaolinite	Appalachian	Ouachita	Florida	Northwestern Africa
Illite	30	86	7.6	3.0
Chlorite	3	13	1.4	1.2
Kaolinite	1	1	1	1.0

CHAPTER IX

CONCLUSION

The clay suite of the Paleozoic rocks of Florida is more similar to that of the Paleozoic rocks of northwestern Africa than to the clay suite of the Appalachian and Ouachita rocks. Thus, it is possible that the first two areas had similar source areas during the Paleozoic. Other explanations are possible, but at least the data is positive and agrees with the concept that Florida was a part of the African continent during the Paleozoic.

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